YIL / YEAR 2025
CİLT - SAYI / VOLUME - ISSUE 11 / 2
e-ISSN 2667-8659

KASTAMONU ÜNİVERSİTESİ MEMBA SU BİLİMLERİ DERGİSİ

KASTAMONU UNIVERSITY MEMBA WATER SCIENCES JOURNAL

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

Antalya İli Balıkçılığı ve Balıkçıların Sosyo-Ekonomik Yapısı

Serap Samsun*[1], Naciye Erdoğan Sağlam[1], Dilek Gögebakan[2]

Özet: Araştırmada, Antalya ili balıkçılığı ve balıkçıların sosyo-ekonomik durumları incelenmiştir. Bu amaçla balıkçılar ile yüz yüze görüşme yoluyla, balıkçı teknelerine ait bilgiler, kullanılan av araçlarına ait bilgiler ve balıkçıların sosyo-demografik/ekonomik özelliklerine ait bilgileri belirlemeye yönelik sorular içeren anket uygulanmıştır. Araştırma materyalini Antalya ili sınırları içerisinde ikamet eden balıkçılar oluşturmaktadır. Araştırmada, avcılıkta kullanılan teknelerin %86'sının 10 m'den küçük ve %92'sinin ahşap tekne olduğu belirlenmiştir. Diğer taraftan, balıkçıların %8'i baba mesleği olduğu için, %34'ü ise gelir kaynağı olarak balıkçılık yaptığını beyan etmiştir. Balıkçıların %32'sinin yaşı 50'nin altındadır. Eğitim seviyesi bakımından, %38'i ilkokul mezunu iken, %4'nün lisansüstü program mezunu olduğu anlaşılmıştır. Balıkçıların sadece %78'i balıkçılıktan memnun iken, %25'i balıkçılık dışında başka iş yaptığını belirtmiştir. Balıkçıların %36'sı pahalılıktan dolayı giderlerin arttığını belirtirken, büyük çoğunluğu istilacı türlerin artması, trol balıkçılarının av sahalarına girmesi ve su kirliliği ile sıcaklığının artmasından dolayı balıkçılığın kötüye gittiğini ifade etmiştir.

Anahtar Kelimeler: Antalya, Antalya balıkçılığı, Sosyo-ekonomik yapı

Fisheries of Antalya Province and Socio-Economic Structure of Fishermen

Abstract: In this study, Antalya province fisheries and socio-economic status of fishermen were analyzed. For this purpose, a questionnaire was administered to fishermen through face-to-face interviews, including questions to determine information on fishing boats, information on fishing gear used and information on socio-demographic/economic characteristics of fishermen. The research material consists of fishermen residing within Antalya province. In the research, it was determined that 86% of the boats used in fishing were smaller than 10 m and 92% of them were wooden boats. On the other hand, 8% of the fishermen stated that it was family profession and 34% stated that they choose fishing as a source of income. The age of 32% of the fishermen is below 50 years. In terms of education level, 38% were primary school graduates, while 4% were postgraduate program graduates. While 78% of the fishermen are satisfied with fishing, 25% of them stated that they also do other jobs. 36% of the fishermen stated that expenses have increased due to the high cost. The majority of the fishermen stated that the fishery has deteriorated due to the increase in invasive species, trawlers entering the fishing grounds and the increase in water pollution and temperature.

Keywords: Antalya, Antalya fisheries, Socio-economic structure

Makale Bilgisi (Araştırma)

1 Ordu Üniversitesi, Fatsa Deniz Bilimleri Fakültesi, Balıkçılık teknolojisi Mühendisliği Bölümü, Fatsa, Ordu/Türkiye
2 Akdeniz Su Ürünleri Araştırma, Üretme ve Eğitim Enstitüsü Müdürlüğü, Demre, Antalya/Türkiye
***Sorumlu yazar:**
serapsamsun@hotmail.com

Alıntı: Samsun, S., Erdoğan Sağlam, N., Gögebakan, D. (2025). Antalya İli Balıkçılığı ve Balıkçıların Sosyo-Ekonomik Yapısı, MEMBA Su Bilimleri Dergisi. 11, (2) 152–161.
https://doi.org/10.58626/memba.1728294

Başvuru Tarihi: 22 Ekim 2024
Kabul Tarihi: 26 Mayıs 2025
Yayın Tarihi: 28 Haziran 2025

1. Giriş

Tarım sektörünün bir alt sektörü olarak balıkçılık; başta gıda olmak üzere, sağlık, çevre, turizm ve ulaştırma, imalat ve lojistik sektörleri ile doğrudan veya dolaylı ilişkisi nedeniyle ülkelerin ekonomik faaliyetlerinde önemli bir yere sahiptir. Gıda sektöründe hammadde kaynağı olması, üretimden pazarlamaya istihdam yaratması, besin olarak bir başka eş değerinin olmaması ve katma değer oluşturacak şekilde işlendiğinde ihracat potansiyeli olması ve sektörel faaliyetleri kolaylaştıracak teknolojik gelişmeleri beraberinde getirmesi gibi özellikler balıkçılık sektörünün ekonomik katkılarını anlamak açısından önemlidir (BAKA, 2010; Doğan, 2015).

Üretim ve tüketici arasındaki zincirde yer alan balıkçıların sosyo-ekonomik durumlarının önemle ele alınması, balıkçılıkla uğraşan insanların sorunlarının tespit edilmesi ve beklentilerinin saptanması balıkçılık sektörünün sorunlarının çözümünde kolaylık sağlayacaktır. Aynı zamanda, bir bölgenin sorunlarını araştırmak ve sorunlara çözüm bulmak ülke balıkçılığının genel sorunlarının çözümünü de kolaylaştıracaktır (Altınbaş ve Menekşe, 2000; Yücel, 2006).

Akdeniz'in kıyı kesimi deniz balıkçılığı açısından Hatay, Adana, Mersin, Antalya illeriyle sınırlandırılmakta ve avlanan su ürünleri ile Türkiye ekonomisine katkı sağlamaktadır. Ayrıca bölge insanlarına geçim kaynağı sağlaması açısından da önemli bir yere sahiptir (Erdoğan Sağlam ve Karadal, 2016).

Antalya Körfezi'nin enlem konumu nedeniyle deniz suyu ısısı her mevsim balık üremesine müsait düzeydedir. Ancak bu avantaja rağmen deniz ürünleri anlamında yeterli yenilenme sağlanamamakta ya da bunu sağlayacak kadar kuvvetli bir yapı göstermemektedir. Avlanma için uygun alanların kısıtlılığı, kıyı kesimlerin balık varlığının ve nüfusunun devamı için gerekli sığ alanlardan yoksun oluşu, tuzluluk oranının yüksekliği gibi etkenler balıkçılık potansiyelini kısıtlamaktadır (Yazar, 2010).

Bölgede balıkçılığa yönelik olarak daha önce yapılan çalışmalarda; Antalya ili balıkçılığının turizm sektörü ile etkileşimi (Beğburs ve Kebapçıoğlu, 2006), dip trolü balıkçılığı ile küçük ölçekli balıkçılığın etkileşimi (Kebapçıoğlu, 2014), balıkçılık sektörünün kent ekonomisine katkısını artırmaya yönelik çözüm önerileri (Yazar ve Soyyiğit, 2020) ve balıkçıların örgütlenme eğilimleri (Şen Şensoy, 2020) gibi konular ele alınmıştır. Teknolojinin gelişmesine bağlı olarak en modern cihazların kullanıldığı balıkçılık sektöründe verimli, etkili ve sürdürülebilir şekilde başarı elde etmek için hazırlanan yönetmeliklerin uygulanması gerekmektedir. Uygulanan yönetmeliklerin başarılı ve etkili olması için balıkçılık sektörünün yapısının çok iyi bir şekilde analiz edilmesi gerekmektedir (Mutlu vd., 2018). Bu araştırma ile Antalya ili balıkçılığı analiz edilmeye çalışılmış ve balıkçıların sosyo-ekonomik yapıları araştırılmıştır.

2. Materyal ve Metod

Bu çalışma, 2024 yılında Antalya ili sınırları içerisinde faaliyet gösteren 50 balıkçı teknesi kaptanı/çalışanı ile yüz yüze görüşmeler yapılarak gerçekleştirilmiştir (Şekil 1). Balıkçı teknesi kaptanı/çalışanlarına uygulanan anket formları, daha önce benzer konularda yapılmış anket formlarının araştırma kapsamına uyacak şekilde revize edilmesiyle hazırlanmıştır.

Araştırma materyalini Antalya ili sınırları içerisinde ticari amaçlı su ürünleri avcılığı yapan, uzatma ağları, olta ve paraketa gibi av araçlarını kullanan balıkçı gemilerinin kaptanları/çalışanları oluşturmaktadır. Araştırma örneklemini, kolayda (kolay erişilebilir) örnekleme (Ural ve Kılıç, 2006) yoluyla ulaşılan 50 gönüllü katılımcı balıkçı oluşturmaktadır. Örneklem büyüklüğünün belirlenmesinde; $n=(N*t^2*P*Q)/(d^2*(N-1)+t^2*P*Q)$ eşitliğinden yararlanılmıştır (Sümbüloğlu ve Sümbüloğlu, 2005). Eşitlikte; N; Evren büyüklüğü, n: Örnekleme büyüklüğü, P: Olayın gerçekleşme olasılığı, Q=(1-P): Olayın gerçekleşmeme olasılığı, t: Güven katsayısı (%5'lik hata payı için bu sayı 1,96), d: olayın görülüş sıklığına göre kabul edilen örnekleme hatasıdır.

Araştırmada, balıkçı teknelerine ait bilgiler (tekne boyu, yaşı, motor gücü, yapı malzemesi gibi), balıkçı teknesinde kullanılan av araçlarının özelliklerine ait bilgiler (ağ göz açıklığı, ağ materyali, kullanıldığı derinlik, hedef tür, gibi) ve tekne ile avcılık yapan balıkçıların sosyo-demografik/sosyo-ekonomik özelliklerine ait bilgiler (yaş, eğitim durumu, balıkçılık tecrübesi, sosyal güvence durumu, mülkiyet durumu, gibi) gibi temel konular ele alınmıştır. Verilerin değerlendirilmesinde frekans dağılımları ve yüzde oranlar kullanılmış olup, düzenlenmesi ve analiz edilmesi Microsoft Excel ortamında gerçekleştirilmiştir.

Şekil 1. Araştırma sahası

3. Bulgular

Araştırma bulguları, çalışmanın amacı doğrultusunda teknelerin fiziksel ve teknik özellikleri, balıkçıların sosyo-ekonomik özellikleri, balıkçıların demografik özellikleri ve kullanılan av araçlarına ait özellikler olmak üzere 4 ayrı aşamada ele alınmıştır.

Balıkçı teknelerinin teknik ve fiziksel özellikleri

Katılımcıların 42 adedi tekne sahibi, 1 adedi ortak ve 7 adedi çalışanlardan oluşmaktadır. Teknelerin boyları 6,0-12,3 m arasında değişiklik göstermekte ve %32'lik oranla 8-8,9 m boy uzunluğundaki tekneler çoğunluğu oluşturmaktadır. %92'si ahşap olan teknelerin yaşları 1-47 arasında değişmektedir (Tablo 1).

Tablo 1. Balıkçı teknelerinin özellikleri

	Adet	Yüzde (%)
Teknenin boyu (m)		
6,0-6,9	4	8
7,0-7,9	12	24
8,0-8,9	16	32
9,0-9,9	11	22
10,0-12,5	7	14
Teknenin yaşı (Yıl)		
1-5	2	4
6-10	12	24
11-15	6	12
16-20	10	20
21-25	5	10
26-30	3	6
31-39	4	8
40 ve üzeri	8	16
Teknenin motor gücü (HP)		
10-29	16	32
30-49	10	20
50-69	4	8
70-89	5	10
90-109	4	8
110-129	2	4
130-149	4	8
150 ve üzeri	5	10
Teknenin yapı malzemesi		
Ahşap	46	92
Fiberglas	3	6
Sac	1	2

Teknede çalışan kişi sayısı (Adet)		
1	38	76
2	12	24
Teknedeki göreviniz nedir?		
Kaptan	48	96
Çalışan	2	4
Bu teknedeki çalışma süreniz (Yıl)		
1-3	17	34
4-6	6	12
7-9	7	14
10-12	11	22
13 ve üzeri	9	18

Balıkçıların demografik özellikleri

%78'i evli olan balıkçıların yaşlarının 23-77 arasında değiştiği, %38 ile çoğunluğun ilkokul mezunu olduğu, ailedeki kişi sayısının %70'inde 3-4 kişiden oluştuğu tespit edilmiştir. Balıkçıların %16'sının eşleri çalışmakta olup, eşlerin %38 ile çoğunluğunun lise mezunu olduğu belirlenmiştir (Tablo 2).

Tablo 2. Balıkçıların demografik özellikleri

	Adet	Yüzde (%)
Cinsiyet durumu		
Erkek	50	100
Kadın	0	
Yaş grupları (Yıl)		
20-29	2	4
30-39	5	10
40-49	9	18
50-59	20	40
60-69	9	18
70-79	5	10
Medeni hali		
Bekar	6	12
Dul	5	10
Evli	39	78
Çocuk sayısı (Adet)		
1	8	16
2	24	48
3	6	12
4	2	4
5	1	2
Çocuk yok	3	6
Bekar	6	12
Balıkçının öğrenim durumu		
İlkokul	19	38
Ortaokul	7	14
Lise	14	28
Önlisans	3	6
Lisans	5	10
Lisansüstü	2	4
Balıkçı eşlerinin öğrenim durumu		
İlkokul	11	28
Ortaokul	6	15
Lise	15	38
Lisans	6	15
Önlisans	1	3
Balıkçı eşlerinin çalışma durumu		
Çalışıyor	8	16
Çalışmıyor	28	56
Emekli	3	6
Dul/bekar	11	22

Ailedeki kişi sayısı (Adet)		
1-2	5	10
3-4	35	70
5-6	7	14
7-9	3	6

Balıkçıların sosyo-ekonomik özellikleri

Katılımcıların %82'sinin sosyal güvencesinin olduğu ve %34 ile çoğunluğun gelir amaçlı, %8 ile en düşük oranda ise baba mesleği olması nedeniyle balıkçılık yaptıkları belirlenmiştir. Balıkçıların %88 ile çoğunluğu kooperatif üyesi olmakla birlikte %12'si 12 ay boyunca balıkçılık yaptığını; %50'si ise sezon dışında başka işlerde çalıştıklarını belirtmişlerdir (Tablo 3). Kooperatife üye olan katılımcıların %27'si "kooperatiften beklentiniz nedir?" sorusuna beklentileri olmadığı cevabını vermişlerdir. Katılımcıların kooperatiften beklentileri değerlendirildiğinde %25 ile çoğunluğu tekne-ağ bakım ve onarımları için mali destek sağlanmasını beklediklerini belirtmişlerdir. Balıkçıların desteklenmesi ve örgütlenme, sosyal imkanların sağlanması, pazarlama imkanlarının arttırılması, çevre düzenlemesi ve temizlik gibi konularda da kooperatiflerden beklentilerinin olduğu tespit edilmiştir.

Tablo 3. Balıkçıların sosyo-ekonomik durumları

	Adet	Yüzde (%)
Sosyal güvenlik durumu		
Var	41	82
Yok	9	18
Meslek tecrübesi (Yıl)		
1-10	16	32
11-20	9	18
21-30	10	20
31-40	8	16
41-50	4	8
51 ve üzeri	3	6
Balıkçılığı seçme nedeni		
Baba mesleği	4	8
Gelir kaynağı	17	34
Ek gelir	9	18
Hobi	12	24
Hobi amaçlı başlangıç sonra gelir kaynağı	8	16
Balıkçılıktan memnuniyet durumu		
Memnun	39	78
Memnun değil	11	22
Kaç kuşaktır balıkçılık yaptığı		
1	33	66
2	12	24
3	4	8
4	1	2
Kaç ay çalıştığı		
1-3	9	18
4-6	15	30
7-9	7	14
10-12	19	38
Sezon dışında ne iş yaptığı		
12 ay balıkçılık	6	12
Tekne, ağ bakımı	9	18
Emekli	10	20
Başka iş (kamu, ticaret, çiftçi, yat kaptanlığı gibi)	25	50
Balıkçılıkla ilgili kredi kullanımı		
Evet	7	14
Hayır	43	86
Kooperatife üyeliği		
Evet	44	88
Hayır	6	12
Ev mülkiyeti		

Var	39	78
Yok	11	22
Otomobil mülkiyeti		
Var	36	72
Yok	14	28
Avladığı ürünü pazarlama şekli		
Kooperatif/toptan/perakende	25	50
Toptan/perakende	24	48
Satış yapmıyor	1	2

"Balıkçılığın güzel ve kötü yanları nedir?" sorusuna, güzel yönleri olarak, katılımcıların tamamı denizin huzur verdiği ve özgür hissettirdiği cevabını vermiştir. Kötü tarafları olarak ise %36'sı balıkçılık giderlerinin artması, %32'si kötü hava koşulları, %6'sı statü olarak balıkçılığın hakir görülmesi ve %5'i olumsuz bir tarafının olmadığını belirtmiştir. Bunların yanı sıra aileden uzak kalma, istilacı türler ve ağlardan balık çıkmaması gibi durumlar da olumsuzluk olarak belirtilmiştir.

"Akdeniz balıkçılığının geleceği için ne düşünüyorsunuz?" sorusuna katılımcıların tamamı balıkçılığın kötüye gittiği cevabını vermiştir. Balıkçılar ayrıca, istilacı türlerin çoğalması, trol balıkçılarının av sahalarına girmesi, su kirliliği ve sıcaklığının artması, bilinçsiz avcılık, yunus ve fokların ağlara zarar vermesi, otel atıklarının kirlilik oluşturması, ruhsatsız amatör balıkçıların çoğalması gibi nedenlerin balıkçılığı olumsuz etkilendiğini ifade etmişlerdir.

Kullanılan av araçlarına ait özellikler

Barbun Ağı: Barbun avcılığında kullanılan uzatma ağlarının göz açıklığı 20-24 mm arasında değişmekte olup ağ materyalleri poliüretan ip/naylon (PU), polipropilen (PP), poliester (PES) ve monofilamentten oluşmaktadır. Barbun ağları, kumlu, çamurlu dip yapısına sahip, 15-150 m arasındaki derinliklere düz ya da zikzak şeklinde atılmaktadır. Ağın suda bekleme süresi 1-10 saat arasında değişmektedir. Hedef tür olan barbunya balığının yanı sıra, lahoz, kupes, izmarit, isparoz, sardalya, mercan, gümüş, hani, kolyoz, vatoz, köpek balıkları ve istilacı türler (balon, aslan, sokar, yalancı isparoz gibi) yakalanmaktadır. Barbun ağları ile tüm yıl boyunca avcılık yapılmaktadır.
Karides Ağı: Karides ağlarının göz açıklığı 20-25 mm arasında değişmekte olup, ağ materyali monofilament, PES ve PU'dan oluşmaktadır. Kumlu, çamurlu ve taşlık dip yapısına sahip 8-100 m arasındaki derinliğe sahip sulara atılmaktadır. Düz ya da zikzak şekilde atılan ağın suda bekleme süresi 12 saattir. Bu ağlara karides dışında barbun, lahoz, iskorpit, kolyoz, kupes, izmarit, isparoz, sardalya, vatoz, mercan türleri, kabuklu ve yengeç türleri ile istilacı türler de yakalanmaktadır. Karides ağları ile avcılık mart-haziran arasında yoğun olmakla birlikte tüm yıl boyunca yapılabilmektedir.
Palamut Ağı: Palamut avcılığında kullanılan ağların göz açıklığı 40-50 mm arasında değişmekle birlikte, ağ materyali monofilament, PU ve PES malzemedir. 5-60 m arasındaki derinliğe ve kumlu, çamurlu, kayalık dip yapısına sahip sularda 2-12 saat bekletilmek suretiyle avcılık yapılmaktadır. Ağlar denize düz şekilde bırakılmaktadır. Bu ağlarla Palamut dışında akya, istavrit, lahoz, sinarit, kolyoz, kupes balıkları yanında balon balığı ve mavi yengeç de yakalanmaktadır. Palamut ağları ile avcılık eylül-mayıs ayları arasında gerçekleşmektedir.
Paraketa: Araştırma bölgesinde, kılıç ve orkinos avcılığında kullanılan paraketaların iğne numarası 1-2 no olmakla birlikte diğer türler için 6-14 no arasında değişen iğneler kullanılmaktadır. Misinadan donatılan paraketalar kumlu, çamurlu ve taşlık dip yapısına sahip 13-500 m arasındaki derinliklere bırakılmaktadır. Düz ya da zikzak şekilde atılmakta olup suda bekleme süresi 2-12 saat arasında değişmektedir. Paraketalarla hedef tür olarak lahoz, mercan, sargos, deniz çipurası, sinarit, bakalyaro, mezgit, orfoz, akya, orkinos ve kılıç balığı avlanmaktadır. Paraketalara hedef türler dışında vatoz, yılan, köpek balığı ve istilacı türlerde yakalanmaktadır.
Sardalya Ağı: 18-20 mm arasında değişen göz açıklığına sahip sardalya ağları PU, PP ve PES materyalden oluşmaktadır. Yüzeyde kullanılan bu ağlar 15-100 m arasındaki sulara düz bir şekilde atılarak 2-4 saat arasında bekletilmektedir. Hedef tür olan sardalyanın dışında kolyoz, palamut, sargos, istavrit, turna ve uçan balıkta avlanmaktadır. Sardalya ağları nisan-temmuz ayları arasında yoğun olarak kullanılmaktadır.
Uzatma Ağı: Antalya bölgesinde kullanılan uzatma ağları 22-28 mm göz açıklığında, monofilament ve PES materyaldendir. Taşlı, kumlu dip yapısına sahip, 15-20 m derinliğe zikzak şekilde bırakılarak 3-12 saat bekletilmektedir. Tüm yıl boyunca kullanılan uzatma ağları ile barbun, sarı kuyruk ve sokar balığının yanı sıra balon, aslan mercan, vatoz ve fangri balıkları da yakalanmaktadır.
Voli Ağı: Araştırma bölgesinde kullanılan voli ağlarının göz açıklığı 24-50 mm arasında değişmekte olup, monofilament, misina, PU ve PES malzemeden oluşmaktadır. Kumlu, çamurlu, taşlı dip yapısına sahip 5-160 m arasındaki derinlikteki sulara düz ya da zikzak şekilde atılarak 3-12 saat arasında bekletilmektedir. Voli ağları hedef tür olarak çipura, akya, kefal, lahoz, turna, sargos, levrek, fangri, sinarit, mırmır, granyuz, melanur türleri için kullanılmaktadır. Bu türler dışında vatoz, köpek balığı, iskorpit, yengeç türleri ve istilacı türler de avlanmaktadır. Voli ağları ekim-mart ayları arasında yoğun olarak kullanılmaktadır.

4. Tartışma

Çalışmada kapsamı içerisinde Antalya ili balıkçılarının sosyo-ekonomik yapısı, balıkçılık faaliyetinde bulunan bulunan balıkçı teknelerinin genel özellikleri ve kullanılan av araçları incelenmiştir.

Adana Karataş ilçesinde kullanılan teknelerin çoğunluğunun 9,6-12,5 m boyunda, 6-10 yaşında ve 201-300 Hp motor gücünde olduğunu bildirmişlerdir (Kurt vd., 2021). Ayyıldız ve Balık (2019) Yalova ilinde yürüttükleri çalışmada balıkçı teknelerinin %87'sinin 12 m'den küçük kıyı balıkçılığı yapan teknelerden oluştuğunu, yapı malzemesinin ise %91'inin ahşap, %9'unun sac olduğunu bildirmiştir. Doğan ve Gönülal (2011), Gökçeada'da %50,0'lık oran ile 6,0-7,9 metre boy uzunluğundaki teknelerin çoğunluğu oluşturduğunu, tekne yaşlarının 3 ile 30 yıl arasında değişmekle birlikte %33,3'lük en yüksek oranla 6 ile 10 yaş arasındaki teknelerin kullanıldığını belirtmiştir. Hatay, Adana, Mersin ve Antalya bölgesinde yürütülen çalışmada %91'i ahşap materyalden yapılmış teknelerin %78'inin 10 m'den küçük olduğu ve ahşap teknelerin daha fazla kullanılmasının, su aldıklarında kolay batmamaları, bakım ve onarımlarının basit ve ucuz olduğu, kıyıya kolayca çıkarılabilmeleri gibi nedenlerden kaynaklandığı belirtilmiştir. Aynı çalışmada kullanılan teknelerin %49'unun 1-50 Hp arasında, %32'sinin 51-200 Hp arasında motor gücüne sahip olduğu bildirilmiştir (Erdoğan Sağlam ve Karadal, 2016). Can vd. (2012), İskenderun Körfezi'nde yürüttükleri çalışmada, kıyı balıkçılığında kullanılan teknelerin boyunun 6-9 m, motor güçlerinin ise 6,5-105 Hp arasında değiştiğini bildirmişlerdir. Mevcut çalışmada incelenen balıkçı teknelerinin %86'sının 10 m'den küçük kıyı balıkçılığı yapan teknelerden oluştuğu, %72'sinin 10 yaşından büyük, %92'sinin yapı malzemesinin ahşap ve %52'sinin motor gücünün 50 Hp'nin altında olduğu tespit edilmiştir. Bakım ve onarımlarının basit ve ucuz olması gibi avantajlarından dolayı benzer çalışmalarda olduğu gibi bu çalışmada da teknelerin çoğunluğunun yapı malzemesini ahşap oluşturmaktadır. Teknelerin boyları, kullandıkları av araçları ve avcılık şekli motor gücünün belirlenmesinde etkili olmaktadır.

Kurt vd. (2021), Karataş tekne balıkçılarının %39,2 ile çoğunluğunun 31-40 yaş aralığında, %46'sının ilkokul mezunu, %80'inin evli, evli olan 59 balıkçının eşlerinin 23'ünün ortaokul, 20'sinin ilkokul ve 16'sının lise mezunu, yine evli olan 59 balıkçının 27'sinin 1-2, 18'inin 3-4, 6'sının 5+ çocuğu varken, 8'inin çocuğunun olmadığı bildirilmiştir. Şahin ve Özekinci (2020), Çanakkale ili balıkçılarının yaş dağılımında, 45-59 yaş grubunun %51,24 ile en fazla orana sahip olduğunu, 16-25 yaşlarında balıkçıya rastlanılmadığını, %46.69'u gibi büyük çoğunluğunun ilkokul öğrenimine sahip olduğunu, %84,30'unun evli ve bunların %56,86'sının 2 çocuk sahibi olduğunu bildirmişlerdir. Akdeniz'de balıkçıların yaşlarının %56'sının 31-50 yaş arasında, %7'sinin 30 yaşından küçük, %66 ile çoğunluğun ilkokul, %1'inin ise üniversite mezunu olduğu, %82'sinin evli, %54'ünün 0-3, %44'ünün 4-7 arasında, %2'sinin ise 7'den fazla çocuğu olduğu belirtilmiştir (Erdoğan Sağlam ve Karadal, 2016). Sağlam vd. (2014), Ayvalık balıkçılarının yaş dağılımının 25-60 arasında değiştiğini, %97'sinin evli, %47'sinin ilkokul, %26'sının ortaokul, %21'inin lise ve %5'inin ise yüksekokul mezunu olduğunu bildirmişlerdir. Bu çalışmada Antalya ili kıyı balıkçılarının %40 ile çoğunluğunun 50-59 yaş aralığında olduğu, %78'inin evli, %48'inin 2, %6'sının 4-5 çocuğu olduğu, %38'inin ilkokul, %14'ünün ortaokul, %28'inin lise, %16'sının üniversite ve %4'ünün lisansüstü programdan mezun olduğu tespit edilmiştir. Yapılan araştırmalar, çalışma koşullarının ağır olması sebebiyle gençlerin balıkçılığa olan ilgilerinin azaldığını göstermektedir. Bu konuda yapılan çalışmalarda çoğu balıkçı en az temel eğitim düzeyinde bir okul mezunu olup, mevcut çalışmada diğer araştırmalardan farklı olarak yükseköğrenim mezunlarının %20 gibi yüksek bir orana sahip olduğu görülmektedir. Ayrıca balıkçı eşlerinin de %18 oranında yükseköğrenim düzeyinde öğrenime sahip olması, balıkçıların eğitim düzeyi ile eşlerinin eğitim düzeyleri ve oranları arasında bir benzerlik olduğunu göstermektedir. Sosyo-demografik özelliklerde farklı bölgelerde yapılan çalışmalarda benzerlikler olabileceği gibi farklılıklarında olması muhtemeldir. Çünkü bölgelerin sosyal yapıları ile ekonomik ve eğitim imkanlarındaki farklılıklar araştırma sonuçlarına da yansımaktadır.

Kurt vd. (2021), Karataş balıkçılarının tamamının sosyal güvenceye sahip olduğunu, %56,8'nin balıkçılığı seçme nedeni olarak babadan kalma meslek olmasını gerekçe gösterdiği, %78'inin sadece balıkçılıktan geçimini sağladığını bildirmişlerdir. Şahin ve Özekinci (2020), Çanakkale ili balıkçılarının %91'inin sosyal güvencesi olduğu, balıkçıların %78,93'ünün kendi evinde oturduğu, %55,79'unun otomobil sahibi olduğu, %35,54'ünün baba mesleği, %32,23'ünün zorunluluktan, %29,75'inin ise sevdiği için bu mesleği yaptığı, %36,37'sinin balıkçılık dışında bir mesleğe sahip olduğu belirtilmiştir. Balıkçıların %61,57'sinin bir kooperatife ortak olduğu aynı çalışmada, %29,75 ile çoğunluğun 21-30 yıl, %15,29'unun ise 40 yılın üzerinde balıkçılık yaptığı, %5,79'unun balıkçılığa emeklilikten sonra başlamış yada tayfa olarak çalışanlardan oluştuğu, %90,50'sinin avladıkları ürünleri komisyoncu aracılığıyla pazarladıkları ifade edilmiştir. Akdeniz Bölgesi'nde yürütülen çalışmada balıkçıların % 61'inin ev sahibi, %39'unun kiracı olduğu, %3'ünün 45 yıldan fazla süredir, %90'ının ise ortalama 30 yıldır balıkçılık yaptığı, %56'sı balıkçılıktan memnun olmadığı ve ileride bırakmayı düşündüğü, %25'inin baba mesleği olması, %31'inin deniz tutkusundan kaynaklı hobi olarak, %44'ünün ise zorunluluktan balıkçılık yaptığı, %78'inin geçimini yalnızca balıkçılıktan sağladığı ve %72'sinin sosyal sağlık kuruluşlarına üye olduğu tespit edilmiştir. Aynı çalışmada balıkçıların %24'ünün balığa çıkma süresinin 6-9 ay, kalan kısmın ise 9 aydan fazla olduğu, %72'sinin kooperatif ve birliklere üye olduğu, %79'unun avladıkları ürünü komisyoncular aracılığı ile %16'sının kendi teknelerinden satış yaparak, %5'inin ise kooperatifler aracılığıyla pazarlama yaptığı bildirilmiştir (Erdoğan Sağlam ve Karadal, 2016). Ayyıldız ve Balık (2019), Yalova ili balıkçılarının %67'sinin mülkiyeti kendisine ait olan evde ikamet ettiğini, tamamının sosyal güvencesinin olduğunu, %80'inin zorunluluktan, %18'inin baba mesleği olmasından, %2'sinin ise deniz tutkusundan dolayı balıkçılık yaptığını, %70'inin 16-45 yıl, %25'inin 0-15 yıl, %5'inin ise 45> yıl balıkçılık deneyimi olduğunu, %10'unun balıkçılık dışında başka bir gelir kaynağının bulunmadığını, % 70'inin gelir yetersizliği ve çalışma şartlarının ağırlığından dolayı memnun olmayıp gelecekte bu mesleği bırakmayı düşündüğünü, %95'inin kooperatif üyesi olduğunu, balıkçıların %60'ının komisyoncular ve %24'ünün kooperatifler aracılığıyla, %16'sının da kendisinin doğrudan tüketiciye avladıkları ürünleri pazarladıklarını bildirmişlerdir. Mevcut çalışmada balıkçıların %82'sinin sosyal güvencesinin olduğu, %52'sinin 20 yıl ve daha fazla mesleki tecrübeye sahip olduğu, %8'inin baba mesleği olması, %34'ünün gelir kaynağı olmasından dolayı balıkçılık yaptığı, %78'inin balıkçılıktan memnun olduğu, %38'inin 10-12 ay çalıştığı, %35'inin emekli veya balıkçılıktan başka bir işte çalıştığı tespit edilmiştir. %88'inin kooperatif üyeliği bulunan balıkçıların %78'inin ev, %72'sinin otomobil mülkiyetinin olduğu, %50'sinin ürünlerini kooperatif aracılığıyla pazarladıkları belirlenmiştir. Sosyal güvence ve mülkiyet sahipliği günümüz koşullarında oldukça büyük öneme sahip kavramlardır. Katılımcıların sosyal güvence ve mülkiyet durumlarına bakıldığında, balıkçılıktan memnun olanların oranlarıyla benzerlik gösterdiği görülmektedir. Benzer konularda yapılan çalışmalarda geçimini sadece balıkçılıktan sağlayanların ve baba mesleği olarak balıkçılık yapanların oranlarının mevcut çalışmaya göre daha fazla olduğu görülmektedir. Bunun alternatif iş olarak bölgede özellikle turizm sektörünün varlığından kaynaklanabileceği söylenebilir. Özellikle pazarlamada ve bürokratik konularda kolaylıklar sağlaması kooperatif üyeliğinde etkili olmaktadır.

Erdem vd. (2020), Orta Karadeniz'de kıyı balıkçılığında kullanılan av araçlarının tor ve fanya kısımlarındaki materyalinin multifilament (iplik) materyalden oluştuğunu, incelenen mezgit ve barbunya uzatma ağlarının ağ göz açıklığının 36 mm olarak belirtilse de, bu ağların göz açıklıklarının her geçen yıl azalarak 32 mm ye kadar düştüğünü belirtmişlerdir. Kasapoğlu ve Düzgüneş (2017), uzatma ağlarının ağ göz açıklığının 32 mm ve daha altında bir göz açıklığına düşmesiyle ağların uzunluk ve yükseklik gibi boyut ve donam şekillerinin de değişiklik gösterdiğini, bunun sonucunda da küçük ölçekli balıkçılıkta by-catch ve ıskarta oranının arttığını tespit etmişlerdir. Alıçlı vd. (2019), Marmara Ereğlisi'nde 21 çeşit balık ve bir eklem bacaklı türü için değişik özelliklere sahip fanyalı ve sade ağ takımları ile algarna ve çaparilerin kullanıldığını tespit etmişlerdir. Çoğunlukla sade ve fanyalı ağ takımlarının kullanıldığı ilçede 173 adet ağ takımının 140 adedini fanyalı ağ takımlarından oluştuğu (%81) ve balıkçı teknelerinde 2-5 adet farklı av aletinin kullanılabileceği belirtilmiştir. Şahin (2006), Tekirdağ deniz balıkçılığında, 5-10 m arasındaki balıkçı teknelerinde 5 çeşit ağ takımı (gırgır ağı, dip ağı, voli ağı, uzatma ağı ve algarna) kullanıldığını bildirmiştir. Samsun, Ordu ve Giresun ili kıyılarında 6'sı sade, 4'ü fanyalı olmak üzere en fazla kullanılan uzatma ağlarının; mezgit misina ağı, kalkan ağı, zargana ağı, lüfer ağı, barbun misina ağı, palamut ağı, fanyalı barbun ağı, fanyalı voli ağı, fanyalı kefal ağı ve fanyalı lüfer ağı olduğu, ağların tamamının PA materyalden yapıldığı, bunun yanısıra, mezgit ağı, barbun ağı ve fanyalı voli ağının tor kısmı monofilament misina olan ağların da kullanıldığı bildirilmiştir (Samsun ve Emirbuyuran, 2017). Mevcut, çalışmada, balıkçı teknelerinde 1-7 adet farklı av aracının kullanılabileceği tespit edilmiştir. Antalya ili kıyı balıkçılığında yoğun olarak kullanılan av araçları barbunya ağı, palamut ağı, sardalya ağı, karides ağı, voli ağı, uzatma ağları ve paraketalardan oluşmaktadır. Avlanan balık türüne göre 18-50 mm arasında değişen göz açıklığına sahip ağlar poliüretan ip/naylon (PU), polipropilen (PP), poliester (PES) ve monofilament materyalden donatılmıştır. Kumlu, çamurlu ve taşlı dip yapısına sahip sularda düz ya da zik zak şekillerde kullanılan bu av araçları ile çoğunlukla akya, bakalyaro, barbunya, çipura, gümüş, hani, iskorpit, isparoz, istavrit, izmarit, karides, kefal, kılıç, kolyoz, kupes, lahoz, mercan, mezgit, orfoz, orkinos, palamut, sardalya, sargos ve sinarit gibi balıklar avlanmaktadır. Bu türlerin yanısıra vatoz, köpek balıkları, yengeç türleri ve istilacı türlerde (balon, aslan, sokar, yalancı isparoz gibi) hedef dışı tür olarak yakalanmaktadır. Özellikle küçük ölçekli balıkçılıkta kullanılan av araçlarında bir standardizasyonun bulunmaması bölgeden bölgeye hatta balıkçıdan balıkçıya birtakım yapısal özelliklerde farklılıklar görülmesine neden olmaktadır. Ayrıca balıkçılık yapılan bölgelerdeki balık türleri de bu farklılıklar üzerinde etkili olmaktadır.

5. Sonuç

İlçeleriyle birlikte yönetsel sınırları bakımından girinti ve çıkıntılar dahil 640 km kıyı uzunluğuna sahip olan Antalya'da, balıkçılık sektörü bölgedeki diğer sektörlere göre gelişmiş değildir. Antalya'da balıkçılık sektörünün kent ekonomisi açısından etki yaratabilmesinin önemli koşullarından biri de bu sektörün turizm ve yerel miras ile eklemlenme sorunudur (Yazar ve Soyyiğit, 2020). Antalya İli balıkçılığı ve balıkçıların sosyo-ekonomik yapısının araştırıldığı bu çalışmaya göre balıkçılık her ne kadar bölge halkının geçim kaynakları arasında yer alsa da, tüm yıl boyunca avcılık yapmayan ancak sezon dışında teknesinin ve ağlarının bakımıyla meşgul olanlar da dahil, sadece balıkçılıktan geçimini sağlayanların oranı (%30) diğer bölgelerde yapılan çalışmalara göre düşüktür. Bunun nedeninin, özellikle bölgede turizm sektörünün alternatif iş imkanları sağlaması olduğu söylenebilir. Her ne kadar balıkçılık mesleğinin bölgedeki devamlılığı üzerinde dezavantaj olarak görülse de, diğer taraftan turizm sektörü açısından önemli bir konuma sahip olması ve buna bağlı olarak, otellerin ve balık restoranlarının göreceli olarak fazlalığı nedeniyle ürünün pazarlanması aşamasında avantaj olabilir. Mevcut çalışma ve daha önce yapılan çalışmalarda balıkçılık yapan kişilerin çoğunlukla toplumsal statü kaygısı ve gelir memnuniyetsizliği yaşadığı ifade edilse de, katılımcıların %20'sinin yükseköğrenim (önlisans/lisans/lisanüstü) mezunu olduğu ve % 78'inin balıkçılıktan memnun olduğu dikkat çekicidir. Ankete katılan balıkçıların tamamı denizde olmanın huzur verdiğini, kendini özgür ve iyi hissettirdiğini ifade etmiştir. Bu anlamda balıkçılığı hobi amaçlı yada başlangıçta hobi amaçlı olup daha sonra ticari olarak devam ettiğini söyleyenlerin oranının %40 olması bu sonucu desteklemektedir.

Bölge, mavi yengeç, lahoz, sargos, mezgit, barbunya, kupes, mercan, istavrit, palamut, orfoz ve orkinos gibi birçok balık türü açısından verimli olsa da sokar, balon ve aslan balığı gibi istilacı türler balıkçılar tarafından sorun olarak nitelendirilmektedir. Ayrıca trol balıkçılarının av sahalarına girmesi, amatör balıkçıların fazlalığı, yunus ve fokların ağlara zarar vermesi balıkçıların en önemli sorunları arasında yer almaktadır.

Sonuç olarak, bölge halkının geçim kaynağı olarak önemli bir potansiyele sahip balıkçılık sektörünün detaylı bir şekilde ele alınması, yine büyük bir ekonomik öneme sahip olan turizm sektörü ile olumlu derecede etkileşiminin sağlanmasına yönelik çalışmalar yapılması ve bu yönde önlemlerin alınması faydalı olacaktır.

6. Etik Standartlara Uygunluk

a) Yazarların katkıları

1. SS: Çalışmayı tasarladı, verileri yorumladı, makaleyi hazırladı.
2 NES: Çalışmayı tasarladı, verileri yorumladı, makaleyi hazırladı.
3. DG: Veri toplama çalışmalarını yürüttü.

b) Çıkar çatışması

Yazarlar çıkar çatışması olmadığını beyan ettiler.

c) Hayvanların refahına ilişkin beyan

Bu çalışma Deney Hayvanları Yerel Etik Kurul Çalışma protokolünü kapsamamaktadır.

d) İnsan hakları beyanı

Çalışma, Ordu Üniversitesi Sosyal ve Beşerî Bilimler Araştırmaları Etik Kurulu'nun 03/06/2024 tarih ve 2024-100 sayılı kararı ile onaylanmıştır.

7. Kaynakça

Alıçlı, Z.T., Doğan, K. & Altunay, M.A. (2019). Marmara Ereğlisi (Tekirdağ) küçük ölçekli balıkçılık faaliyeti ve balıkçıların sosyo-ekonomik yapısının analizi. Aquatic Research, 2(4), 200-210. doi: 10.3153/AR19019.

Altınbaş, N. & Menekşe, A. (2000). Marine Resources. 'The second marine shura" The Government Marine, Istanbul.

Ayyıldız, M. & Balık, İ., (2019). Yalova İli'nde Deniz Balıkçılığı ve Balıkçıların Sosyo-ekonomik Yapısı, Kent Akademisi, 12 (38), Issue 2, Pages. 288-298.

Batı Akdeniz Kalkınma Ajansı (BAKA) (2010). Antalya'da Tarım Sektörünün Sorunları ve Çözüm Önerileri Çalıştayı. Erişim tarihi: 10.09.2024. https://www.kalkinmakutuphanesi.gov.tr/assets/upload/dosyalar/1557478431antalyatarimcalistayicalismagruplarisonucraporu.pdf adresinden alınmıştır.

Beğburs, C.R. & Kebapçıoğlu, T. (2006). Antalya İli Balıkçılığının Turizm ile Etkileşimi. E.Ü. Su Ürünleri Dergisi, 23(1/3), 355-357.

Can, M.F., Serpin, D. & Can, M.F. (2012). İskenderun Körfezinde Küçük Çaplı Balıkçılığın Genel Durumu: İskenderun, Arsuz ve Konacık Örneği. Atatürk Üniversitesi Vet. Bil. Dergisi, 7(3), 167-175.

Doğan, K. & Gönülal, O. (2011). Gökçeada (Ege Denizi) Balıkçılığı ve Balıkçıların Sosyo-Ekonomik Yapısı. Karadeniz Fen Bilimleri Dergisi, FABA 2011 Sempozyum Özel Sayısı, Yıl:3, Cilt:2, Sayı:5, Sayfa 57-69.

Doğan, K. (2015). Balıkçılık Sektöründe Su Ürünleri Kooperatiflerinin Yeri ve Önemi. 21. Milletlerarası Türk Kooperatifçilik Kongresi, Karabük.

Erdem, Y., Özdemir, S., Özsandıkçı, U. & Büyükdeveci F. (2020). Technical plans of fishing gears used in the central Black Sea coastal fisheries (Sinop-Samsun). Marine and Life Sciences, 2(2), 85-96. (In Turkish).

Erdoğan Sağlam, N. & Karadal, E. (2016). Akdeniz Bölgesi Sahil Şeridi Deniz Balıkçılığının Sosyoekonomik Yapısı. Süleyman Demirel Üniversitesi Eğirdir Su Ürünleri Fakültesi Dergisi, 12(2), 158-169.

Kasapoğlu, N. & Düzgüneş, E. (2017). The common problem in the Black Sea fisheries: By-catch and its effects on the fisheries economy. Turkish Journal of Fisheries and Aquatic Sciences, 17, 387-394.

Kebapçıoğlu, T. (2014). Kuzeydoğu Akdeniz'de (Antalya) Kıyısal Dip Trolü Balıkçılığı ile Küçük Ölçekli Balıkçılığın Etkileşimi. Doktora Tezi, Akdeniz Üniversitesi Fen Bilimleri Enstitüsü, Antalya, Türkiye.

Kurt, M., Şentürk, H., Şentürk. F. & Öz, N. (2021). Karataş tekne balıkçılığının genel durumu. Journal of Social and Humanities Sciences Research, 8(67), 611-623.

Mutlu, C., Uncumusaoğlu, C.M. & Verep, B. (2018). Giresun'un Balıkçılık Faaliyetlerinin Ekonomik Analizi. Karadeniz Fen Bilimleri Dergisi, 8(1), 87-97.

Sağlam, C., Akyol, O. & Demir Sağlam, Y. (2014). Ayvalık (Ege Denizi) Kıyı Balıkçılığı Üzerine Bir Ön Çalışma. Fırat Üniversitesi Fen Bilimleri Dergisi, 26(1), 15-20.

Samsun, S. & Emirbuyuran, Ö. (2017). Doğu Karadeniz Bölgesi kıyı balıkçılığında kullanılan uzatma ağlarının teknik özellikleri. Ege Journal of Fisheries and Aquatic Sciences, 34(3), 269-275.

Sümbüloğlu, V. & Sümbüloğlu K. (2005) Sağlık Bilimlerinde Araştırma Yöntemleri. Örnekleme. Hatipoğlu Basım ve Yayıncılık, Ankara.

Şahin, S. (2006). Tekirdağ İli Deniz Balıkçılığının Sosyo-Ekonomik Durumu ve Pazarlama Yapısı. Yüksek Lisans Tezi, Tekirdağ Üniversitesi Fen Bilimleri Enstitüsü, Tekirdağ, Türkiye.

Şahin, E. & Özekinci, U. (2020). Socio-economic status of small-scale fisheries, Çanakkale (Northern Aegean) Turkey. COMU J. Mar. Sci. Fish, 3(1),19-26. doi: 10.46384/jmsf.740894.

Şen Şensoy, E.B. (2020). Balıkçıların Örgütlenme Eğilimleri: Antalya İli Örneği. Doktora Tezi, Akdeniz Üniversitesi Fen Bilimleri Enstitüsü, Antalya, Türkiye.

Ural, A., & Kılıç, İ. (2006). Bilimsel araştırma süreci ve SPSS ile veri analizi. Ankara: Detay Yayıncılık.

Yazar, A. (2010). Deniz Kültürünün Antalya Kent Kültürü ve Kimliğinin Dönüşümündeki Yeri. Yüksek Lisans Tezi, Akdeniz Üniversitesi Sosyal Bilimler Enstitüsü, Antalya, Türkiye.

Yazar, A. & Soyyiğit, S. (2020). Antalya'da Dinamik Balıkçılık Sektörü İçin Ekonomik Amaçlı Yatay İşbirliği Önerisi: Teknik Kapasitesi Artırılmış Örgütsel Ağ. Uygulamalı Bilimler Fakültesi Dergisi, 2(2), 1-12.

Yücel, Ş. (2006). Orta Karadeniz Bölgesi Balıkçılığı ve Balıkçıların Sosyoekonomik Durumu. Ege Üniversitesi Su Ürünleri Dergisi, 23(1-3), 529-532.

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

Ordu Bölgesi Küçük Ölçekli Balıkçılığın Av Gücü ve Ekonomik Yapısının İncelenmesi

Eray Şensoy[1], Naciye Erdoğan Sağlam[2]*, Serap Samsun[2]

Özet: Su ürünleri üretimi açısından önemli bir potansiyele sahip olan küçük ölçekli balıkçılığın sosyodemografik yapısı, üretim miktarları ve ekonomik durumunun sürekli olarak incelenmesi gerekmektedir. Bu çalışmada, küçük ölçekli balıkçılığın av gücü açısından yapısı incelenmiş ve balıkçıların sosyodemografik yapıları, balıkçılık üretim miktarları ve gelir-gider dengesi üzerinden ekonomik yapılarının belirlenmesi amaçlanmıştır. Yapılan yüz yüze görüşmeler sonucunda, tekne yaşlarının 1 ile 21 arasında değiştiği, avcılıkta kullanılan teknelerin %65.30'luk kısmında echosounder cihazının bulunmakta olduğu, teknelerin %65.27'sinin 5-7.99 m boy uzunluğundaki teknelerden oluştuğu, balıkçıların yaşlarının 25 ile 81 arasında değişim gösterdiği, %54.88'inin sadece balıkçılıktan geçimini sağladığı, balıkçıların %95'inin avlanmada olta, ağ ve algarna kullandığı, avlanan balıkların %87'sinin komisyoncular aracılığıyla satıldığı, en yüksek oranda avlanan ve gelir getiren türlerin barbunya, mezgit, palamut ve deniz salyangozu olduğu, elde edilen gelir olarak 50.000 TL'ye kadar olan grubun en yüksek sayıda olduğu hesaplanmıştır.

Anahtar Kelimeler: Av gücü, Ekonomi, Küçük Ölçekli Balıkçılık, Ordu

Investigation of the Fishing Power and Economic Structure of Small Scale Fishing in Ordu Region

Abstract: The sociodemographic structure, production amounts and economic situation of small-scale fisheries, which have an important potential in terms of aquaculture production, should be continuously examined. In this study, the structure of small-scale fisheries in terms of catch power was examined and it was aimed to determine the economic structure of the fishermen through their sociodemographic structure, fishery production amounts and income-expenditure balance. As a result of face-to-face interviews were calculated the ages of the boats ranged from 1 to 21, 65.30% of the boats used of fish finders. 65.27% of the boats length vary between 5-7.99 m., the ages of the fishermen vary between 25 and 81, 54.88% make a living solely from fishing, 95% of fishermen use fishing gillnet, trammel net and longline for fishing, 87% of the fish caught are sold through brokers, the species that are caught at the highest rate and generate income are red mullet, whiting, Atlantic bonito and sea snails. It has been calculated that the group with income up to 50.000 TL is the highest.

Keywords: Economy, Fishing power, Ordu, Small-Scale Fisheries.

Makale Bilgisi (Araştırma)

[1] T.C. Tarım ve Orman Bakanlığı, Ordu İl Tarım ve Orman Müdürlüğü, Ordu/Türkiye
[2] Ordu Üniversitesi Fatsa Deniz Bilimleri Fakültesi, Balıkçılık Teknolojisi Mühendisliği Bölümü, Ordu/Türkiye
***Sorumlu yazar:** nes-34@hotmail.com

Alıntı: Şensoy, E., Erdoğan Sağlam, N., Samsun, S. (2025). Ordu Bölgesi Küçük Ölçekli Balıkçılığın Av Gücü ve Ekonomik Yapısının İncelenmesi, MEMBA Su Bilimleri Dergisi. 11, (2) 162-171.
https://doi.org/10.58626/memba.1728303

Başvuru Tarihi: 18 Aralık 2024
Kabul Tarihi: 19 Haziran 2025
Yayın Tarihi: 28 Haziran 2025

1.Giriş

Denizlerin, insanlığa sağladığı faydalar düşünüldüğünde sürdürülebilirlik ve verimlilik, deniz kaynakları için hayati önemdedir. Deniz ekosistemindeki türler küçük ya da büyük gruplar oluşturarak, üreme, beslenme, korunma, sığınma amaçlı birbirleriyle etkileşim içerisinde bulunmaktadır. Canlı deniz kaynakları yenilenebilir kaynaklar olup balıkçılığın sürdürülebilirliğini sağlarken etkili ve kapsamlı bir balıkçılık yönetiminin zorunluluğunu da beraberinde getirir. Doğru yönetim sistemlerinin belirlenmemesi durumunda, yenilenebilir kaynaklar tükenebilir kaynaklar durumuna gelebilir (Ünal, 2001; Aksu vd., 2023). Faaliyet alanının bütün yönleriyle bilinmesi ve sektörün içinde bulunduğu durum hakkında yerinde incelemeler ve araştırmalar yapılarak tespit edilmesi, balıkçılık alanında uygulanacak politikaların ve alınacak tedbirlerin etkinliğini arttırır.

Türkiye denizcilik ekonomisinde balıkçılık sektörü önemli bir öneme sahiptir (Eminçe Saygı, 2024). Ülkemizde faaliyet gösteren 18.444 adet balıkçı gemisi incelediğinde bunların %17'si iç sularda, %83'lük kısmı ise denizlerimizde faaliyet göstermektedir. Bu gemilerin %90'ından fazlası küçük ölçekli balıkçı denilen ve 12 m altı gemilerle avcılık yapan balıkçılardan ve kalan %10'luk kısmı ise büyük ölçekli balıkçılardan oluşmaktadır (BSGM, 2023).

Balıkçılık sektörünün gelişmekte olan dinamik bir alt sektörü olan küçük ölçekli balıkçılık faaliyetleri, sezonluk, yarı veya tam zamanlı olarak yerel ve iç pazara balık ve buna bağlı balıkçılık ürünlerini sağlamaktadır (Kurien, 1998). Küçük ölçekli balıkçılık yoksulluğun azaltılması ve geçim kaynağı olarak önemli katkılar sağlamaktadır (Kurien, 1998; Berkes vd., 2001; Béné, 2003; Ünal, 2003).

Bu çalışma ile 2022-2023 yılları itibariyle Ordu İlinde avcılık yapan küçük ölçekli balıkçılığın mevcut av gücü potansiyeli belirlenmeye çalışılmış ve bu kapsamda balıkçıların sosyal ve ekonomik yapısının ortaya konması amaçlanmıştır.

2. Materyal ve Metod

Araştırmada, 2022-2023 yıllarında Ordu ilinde küçük ölçekli balıkçılığın mevcut av gücü potansiyeli ve balıkçıların sosyo-ekonomik yapısı incelenmiştir (Şekil 1). Balıkçılık ve Su Ürünleri Genel Müdürlüğü kayıtlarına göre, Ordu ilinde 9 barınak, 2 çekek yeri ve 1 doğal barınma yerinde su ürünleri avcılığıyla uğraşan tekneler barınmaktadır. Bölgede faaliyette bulunan 12 adet su ürünleri kooperatifinin başkanları, üye ortakları ve kooperatif üyesi olmayan bağımsız balıkçılara anket uygulanmıştır. Teknelerin teknik ve fiziksel özellikleri, teknede çalışan tayfa sayıları, tayfalara yapılan ödeme şekli, balıkçıların yaş ve eğitim durumları, çocuk sayıları, sosyal güvence durumları, balıkçılığı seçme nedenleri, gelir memnuniyetleri, balıkçılıkta karşılaştıkları sorunlar, türlerine göre avlanan su ürünleri miktarları ve bunların nasıl pazarlandığı gibi veriler 164 kişi; av aracı yapısı, giderler (tüketilen mazot, mazota ödenen tutar, tayfaya ödenen tutar, ağ alımı ve bakım onarım, evrak ücreti, gemi bağlama ücreti) ve gelirler (avlanılan türlerden elde edilen tutar ve destekleme tutarı) hakkındaki veriler ise 155 balıkçı ile yüz yüze görüşülerek elde edilmiştir.

Şekil 1. Araştırma sahası

Çalışma süresince yapılan görüşmelerden elde edilen veriler Microsoft Ofis Excel programında düzenlenerek tablo ve grafikler halinde sunulmuştur.

3.Bulgular

3.1. Küçük ölçekli balıkçılıkta kullanılan teknelere ve balıkçılık faaliyetlerine ait bilgiler

Küçük ölçekli balıkçılıkla uğraşan ruhsat sahibi teknelerin %2'den fazlası 0-4.99 m aralığında; %65'i 5-7.99 m aralığında; yaklaşık %29'u 8-9.99 m aralığında ve kalan %4'e yakın kısım ise 10-11.99 m aralığında boy dağılımlarına sahiptir. Teknelerde kullanılan teknik cihazlar içerisinde %65.30 ile echosounder cihazının en yüksek orana sahip olduğu belirlenmiştir. Tekneleri tamamı ahşap materyalden yapılmış olup, %75.09'unun 6-10 yaş arasında olduğu tespit edilmiştir. Balıkçıların %86.61'inde günlük çalışma saatlerinde en yüksek oran 4-6 saat arası çalışma olarak kayıt edilirken, yıllık av süresi değerlendirildiğinde %46.37'si en yüksek oran 90 gün, %4.87'si en düşük oran 180 gün olarak hesaplanmıştır. Balıkçıların %86.58'i balığını komisyoncu aracılığı ile satmaktadır (Tablo 1).

Ordu ilinde küçük ölçekli balıkçıların kullandıkları av araçlarının %64.65 ile çoğunluğu uzatma ağlarından oluşmaktadır. Bunu %21.91 ile fanyalı uzatma ağı, %9.29 ile olta, %2.43 ile voli ağı, %0.91 ile serpme ve %0.80 ile algarna izlemektedir.

Tablo 1. Ordu İli Balıkçı Teknelerinin Özellikleri

	Adet	%
Tekne Boyu (m)		
0-4,99	4	2,43
5,0-7,99	107	65,27
8,0-9,9	47	28,65
10,0-11,99	6	3,65
Teknik Cihazlar		
Telsiz	4	2,43
Sonar	1	0,60
Echosounder (Balık Bulucu)	108	65,30
Derinlik ölçer	47	28,65
Pusula/Navigasyon	26	15,85
Su üstü radarı	0	0
GPS/Satallite	33	20,12
Tekne Yaş Dağılımı (yıl)		
"1-5"	48	29,36
"6-10"	75	45,73
"11-15"	18	10,97
"16-20"	12	7,31
21 ve üzeri	11	6,73
Günlük Çalışma Süresi (sa)		
"4-6"	142	86,61
"6-8"	15	9,14
"8-10"	5	3,04
>10	2	1,21
Yıllık Av Süresi (gün)		
90	76	46,37
120	10	6,09
150	33	20,12
180	8	4,87
210	19	11,58
240 ve üzeri	18	10,97
Avlanılan Balığı Satış Şekli		
Perakende	22	13,42
Komisyoncu	142	86,58
Teknenin Yapısı		
Ahşap	164	100
Sac	0	0
Fiber	0	0

3.2. Balıkçıların demografik özelliklerine ait bilgiler

Katılımcıların %4'lük kısmını oluşturan kadın balıkçıların, tekne sahibi olmasalar bile avlama işleminden sonra ağ temizleme ve bakım onarım işlemlerine büyük oranda katkı sağladıkları belirlenmiştir. Bölgedeki küçük ölçekli balıkçıların yaşları incelendiğinde 25-81 yaş aralığında dağılım gösterdiği, %64'ünün 50 yaşından büyük olduğu ve balıkçıların genel yaş ortalamasının ise 53 olduğu görülmüştür (Tablo 2).

Tablo 2. Ordu İli Balıkçılarının Demografik Özellikleri

Balıkçıların Demografik Özellikleri	Adet	%
Cinsiyet Durumu		
Erkek	157	96
Kadın	7	4
Yaş Dağılımları		
20-29	4	3
30-39	17	10
40-49	38	23
50-59	59	36
60 ve Üzeri	46	28
Balıkçılık Dışında İş Durumu		
Emekli veya başka işi olan	74	45,12
Sadece balıkçılık yapan	90	54,88
Medeni Hali		
Bekar	22	13,44
Evli	142	86,56
Öğrenim Durumu		
İlköğretim	123	75,00
Lise	36	21,95
Üniversite	5	3,05
Çocuk Sayısı		
0	38	23,17
1	18	10,97
2	56	34,17
3	38	23,17
4	9	5,48
5 ve üzeri	5	3,04

3.3. Balıkçıların sosyal ve ekonomik özelliklerine ait bilgiler

Balıkçıların sosyal ve ekonomik özelliklerine ait bilgiler Tablo 3'de verilmiştir.

Tablo 3. Ordu İli Balıkçılarının Sosyo ekonomik Özellikleri

Balıkçıların Sosyoekonomik Özellikleri	Kişi Sayısı	%
Sosyal Güvenlik Durumu		
Sosyal güvencesi var	152	92,68
Sosyal güvencesi yok	12	7,32
Meslek Tecrübeleri (yıl)		
1-10	38	23,17
11-20	51	31,09
21-30	28	17,07
31-40	35	21,34
41 ve üzeri	12	7,33
Balıkçılığı Seçme Nedeni		
Aile bütçesine katkı	3	1,82
Baba mesleği	90	54,87
Hobi	19	11,58
İşsizlik/Geçim kaynağı	52	31,73
Mülkiyet Sahibi Olma Durumu		
Ev Sahibi	140	85,36

Kiracı	24	14,64
Gelirden Memnuniyet Durumu		
Çok İyi	1	0,62
İyi	7	4,26
Orta	81	49,36
Kötü	75	45,73
Balıkçılığı Bırakma İsteği		
Var	73	44,51
Yok	91	55,49
Çocuklarının Gelecekte Balıkçılıkla Uğraşmasını İsteme Durumu		
Evet	12	7,32
Hayır	152	92,68

3.4. Balıkçıların bölge balıkçılığının durumuna ilişkin görüşleri

Katılımcılara balıkçılığı etkileyebilecek olası çevresel koşullara yönelik yöneltilen sorulara %65 ile çoğunluğu su kirliliği cevabını vermiştir (Tablo 4).

Tablo 4. Ordu İli Balıkçılarının Bölge Balıkçılığının Durumu ile İlgili Görüşleri

Bu Yıl Avcılık Miktarınızı Etkileyen Çevresel Etmenler	Kişi Sayısı	%
Su sıcaklığının değişimi	49	29,87
Balık göç yollarının değişimi	54	32,92
Su kirliliği	65	39,63
Hava şartlarının değişimi	50	30,48
Müsilaj	1	0,60
Balıkçılıkla İlgili Sorunlar		
Balık stoklarının azalması	116	70,73
Avcılık baskısı	108	65,85
Su kirliliği	69	42,07
Örgütlenmenin yetersizliği	22	13,41
Su ürünleri sanayinin yetersizliği	8	4,87
Bilinçsiz avcılık	37	22,56
Tüketimin az olması	13	7,92
Düzensiz fiyat dengesi	25	15,24
Pazarlamanın yetersizliği	11	6,70
Depolama koşullarının yetersizliği	0	0
Aşırı Avcılığın Engellenmesi İçin Yapılması Gerekenler		
Ava çıkma sürelerinde azalma	46	28,04
Avcılık yapan balıkçı sayısında azalma	31	18,90
Bazı av yasağı bölgeleri oluşturmak	52	31,70
Sefer başına avlanan miktarın sınırlandırılması	56	34,14
Gemi büyüklüğünde sınırlama	65	39,63
Ağ büyüklüğünü sınırlama	84	51,21
Avcılık cihazlarını sınırlama	80	48,78

3.5. Avlanan türler ve piyasa değerleri

Avlanan türler maksimum av miktarı bakımından ele alındığında, barbunyanın (*Red mullet*) 1.000 kg'a, istavritin (*Trachurus trachurus*) 500 kg'a, mezgitin (*Merlangius merlangus*) 3.000 kg'a kadar avlandığı belirlenmiştir (Tablo 5).

Tablo 5. Avlanılan Türlerin Ağırlık ve Kazanç Sınıf Aralıkları (N: Kişi Sayısı)

	Av Miktarı (Kg)	2022 N	2023 N	Kazanç (TL)	2022 N	2023 N

Barbunya	1-1000	85	70	1-50000	88	72
	1001-2000	2	3	50001-100000	1	2
	2001-3000	1	0	100001-150000	0	0
	3001-4000	0	1	150001-200000	0	0
	4001-5000	1	1	200001-250000	0	1
				250001-300000	0	0
İstavrit	1-250	56	39	1-10000	70	47
	251-500	9	25	10001-20000	8	18
	501-750	9	3	20001-30000	1	5
	751-1000	1	6	30001-40000	0	4
	1001-1250	4	2	40001-50000	0	1
Kalkan	1-100	11	11	1-10000	9	7
	101-200	0	0	10001-20000	2	2
	201-300	0	2	20001-30000	0	2
	301-400	2	0	30001-40000	0	0
				40001-50000	2	0
				50001-60000	0	2
Kefal	1-25	1	1	1-500	1	1
	26-50	0	3	501-1000	2	2
	51-75	2	0	1001-1500	0	1
	76-100	0	1	1501-2000	1	0
	101-125	1	0	2001-2500	0	0
				2501-3000	0	1
Mezgit	1-3000	101	102	1-50000	69	66
	3001-6000	22	22	50001-100000	33	36
	6001-9000	2	3	100001-150000	14	12
	9001-12000	3	1	150001-200000	7	11
	12001-15000	0	1	200001-250000	3	2
				250001-300000	1	1
				300001-400000	1	1
Palamut	1-2000	72	76	1-50000	72	64
	2001-4000	11	7	50001-100000	12	14
	4001-6000	1	1	100001-150000	0	5
	6001-8000	0	1	150001-200000	1	1
	8001-10000	1	0	200001-250000	0	0
				250001-300000	0	1
Lüfer	1-100	1	4	1-3000	1	1
	101-200	2	0	3001-6000	2	3
	201-300	0	0	6001-9000	0	0
	301-400	0	1	9001-12000	0	0
	401-500	1	0	12001-15000	1	0
				15001-18000	0	1
Zargana	1-250	2	2	1-10000	3	2
	251-500	2	2	10001-20000	2	0
	501-750	1	1	20001-30000	1	3
	751-1000	1	0	30001-40000	0	0
	1001-1250	0	0	40001-50000	0	0
	1251-1500	0	1	50001-60000	0	0
				60001-70000	0	1
İskorpit	1-100	2	0	1-3000	2	0
	101-200	0	2	3001-6000	0	2
	201-300	0	0	6001-9000	1	0
	301-400	0	1	9001-12000	0	1
	401-500	1	0			
Deniz Salyangozu	1-10000	11	10	1-50000	10	3
	10001-20000	3	4	50001-100000	4	6
	20001-30000	0	0	100001-150000	0	3
	30001-40000	1	0	150001-200000	0	2
	40001-50000	2	1	200001-250000	2	0
	50001-60000	0	2	250001-300000	1	0
				300001-400000	0	0
				400001-500000	0	2
				500001-600000	0	1

3.6. Avlanan toplam av ve elde edilen kazanç

Balıkçıların yıllık toplam av miktarının 2022 yılı için %92,9, 2023 yılı için ise %91 oranları ile çoğunluğunun 1-10.000 kg arasında av elde ettiği belirlenmiştir (Tablo 6).

Tablo 6. 2022 ve 2023 Yılları Toplam Av ve Toplam Kazanç Miktarları (N: Kişi Sayısı)

Toplam Av (Kg)	2022 N	2023 N	Toplam Kazanç (TL)	2022 N	2023 N
1-10000	144	141	1-50000	74	50
10001-20000	6	9	50001-100000	41	45
20001-30000	2	2	100001-150000	15	22
30001-40000	1	0	150001-200000	8	11
40001-50000	1	0	200001-250000	10	10
50001-60000	1	3	250001-300000	1	10
			300001-400000	4	1
			400001-500000	2	1
			500001-600000	0	3

3.7. Giderler

Çalışmada balıkçılık faaliyetleri için, mazot, ağ bakım-onarım ve tayfaya ödenen ücretlerin yanı sıra, giyim, kumanya, gemi bağlama ve belgeler için düzenlenen evraklara ödenen ücretlerde gider olarak bildirilmiştir. Gemi bağlama giderleri yıllık ortalama 2022 ve 2023 yılı için sırasıyla 273 TL ve 465 TL; evrak giderleri ise 2022 ve 2023 yılları için sırasıyla ortalama 1027 TL ve 1842 TL olarak tespit edilmiştir. Balıkçılık faaliyetlerinde mazot, tayfa, ağ alımı ve bakım-onarımına ait giderler Tablo 7'de verilmiştir.

Tablo 7. 2022 ve 2023 Yılları Balıkçılık Giderlerine Ait Bilgiler (N: Kişi Sayısı)

	2022 N	2023 N
Mazota ödenen tutar (TL)		
≤ 7500	50	66
7501-15000	38	34
15001-22500	14	22
22501-30000	20	11
30001-37500	7	10
37501-45000	7	2
45001-52500	7	1
52501-60000	2	3
≥ 60001	10	6
Tayfaya Ödenen Tutar (TL)		
≤ 20000	142	133
20001-40000	13	13
40001-60000	0	6
60001-80000	0	2
80001-100000	0	0
100001-120000	0	0
120001-140000	0	0
140001-160000	0	1
Ağ Alım ve Bakım Onarım (TL)		
≤ 20000	136	101
20001-40000	18	38
40001-60000	1	10
60001-80000	0	4

80001-100000	0	1
100001-120000	0	1
Toplam Gider (TL)*		
1-50000	119	99
50001-100000	26	33
100001-150000	7	12
150001-200000	2	7
200001-250000	1	3
250001-300000	0	1

*Toplam gidere mazot, tayfa ve ağ bakım onarım dışındaki diğer giderlerde dahil edilmiştir.

Balıkçıların kar ve zarar durumlarına bakıldığında, 2022 yılı için %18, 2023 yılı için ise %14'ünün zararda olduğu, 1-50.000 TL'ye kadar olan sınıf aralığının en yüksek (2022 için %53, 2023 için %44) olduğu saptanmıştır (Tablo 8).

Tablo 8. 2022 ve 2023 Yılları Kar-Zarar Durumu (N: Kişi Sayısı)

Kar-Zarar (TL)	2022 N	2023 N
-100000--49999	1	0
-50000-0	27	22
1-50000	82	68
50001-100000	22	35
100001-150000	13	13
150001-200000	6	8
200001-250000	1	4
250001-300000	3	1

4.Tartışma

Ülkemizde küçük ölçekli ya da kıyı balıkçılığı diye adlandırılan balıkçılıkta kullanılan teknelerin boy, motor gücü, teknik cihazlar ve yapım malzemelerini kapsayan çalışmalar bulunmaktadır. İstanbul ilinde 1-4.9 m (%3.98), 5-7.9 m (%53.82), 8-9.9 m (%34.31) ve 10-11.9 m (%7.89) uzunluğundaki teknelerin tercih edildiği; %35'inin ekosounder, %30'unun GPS, %15'inin radar cihazı, %9'unun telsiz ve %7'sinin ise sonar cihazı kullandığı; %91.43 ahşap, %4.87 fiber ve %3.71 sac malzemeden üretildiği (Çiftçi, 2019), Marmara Ereğlisi'nde 5.28-10.8 m ve motor güçlerinin 5.58-175.13 HP arasında değiştiği, tekne yapım malzemelerinin ahşap olduğu (Alıçlı vd., 2019), Ordu ilinde 5-12 m arasında değiştiği ve tamamının ahşap olduğu (Çalık ve Erdoğan Sağlam, 2015), Kocaeli ilinde teknelerin %10'unun sac, %86.67'sinin ahşap ve %3.33'ünün fiberglas; Bursa ilinde ise %17.27'sinin sac, %79.31'inin ahşap, %3.45'inin ise fiberglas malzemeden yapıldığı (Düz, 2011); Karasu (Sakarya) ilçesinde tekne uzunlukları çoğunlukla 6.5-9.5 m arasında değişirken (%75), 50 HP den düşük güce sahip olan teknelerin yarıdan fazla olduğu (%57.14) (Uzmanoğlu ve Soylu, 2006) bildirilmiştir. Şahin (2006), Tekirdağ ili deniz balıkçılığında 5-10 m arasındaki balıkçı teknelerinde pusula, radar, sonar, echo-sounder, telsiz, vinç ve GPS satalayt cihazlarının kullanıldığını bildirmiştir. Bu çalışmada küçük ölçekli balıkçılık kapsamında teknelerin %65.27'sinin 5-7.99 m boy aralığında olduğu ve küçük ölçekli balıkçılar tarafından kullanılan avlanma araçlarının balıkçı gemisi, uzatma ağları, olta ve algarna olduğu, %65.30'luk kısmında balık bulucu olarak echosounder bulunduğu, teknelerin genellikle küçük boyda teknelerden oluşması ve fazla uzak mesafelerde avcılık yapamamaları nedeni ile telsiz, sonar cihazı ve pusula gibi donanımlara ihtiyaç duymadıkları belirlenmiştir. Avlanılacak türe bağlı olarak uzatma ağları ve oltaların atılacağı derinlikleri belirlemek amacıyla, derinlik ölçer, denize bırakılan ağların koordinatlarını belirlemek ve meralarını konumlamak amacıyla da GPS/Satellite kullandıkları belirlenmiş, su yüzeyindeki irili ufaklı cisimleri tespit eden ve daha çok büyük ölçekli balıkçıların kullandığı su üstü radarına ise bölgedeki küçük ölçekli balıkçılarda rastlanmamıştır. Yine çalışmaya katılan balıkçıların %15'inden fazlasının denizde yer-yön tayinini sağlamak ve rotalarını oluşturmak amacıyla pusula/navigasyon kullandıkları belirlenmiştir. Bu araştırmada teknelerin yaşları 1-21 arasında olup, yarısına yakını 11-15 yaş aralığındadır. Yapım ve bakım masraflarının ucuzluğu nedeniyle tüm teknelerin ahşap malzemeden imal edildiği tespit edilmiştir. Gerekli bakımlar yapılsa bile ahşap teknelerin ortalama ömrünün 20-25 yıl olduğu, bölgedeki fiber teknelerin çoğunun küçük boyda olduğu ve amatör olarak avcılık yaptığı gözlemlenmiştir.

Ordu ilinde daha önce yapılan çalışmalarda, 12 metre altındaki teknelerle avcılık yapan balıkçıların yıl boyunca denizde geçirdikleri vaktin ortalama 185.1±8.49 gün olduğu, %49'unun yıl içinde 200 günden fazla denizde avcılık yaptığı (Köse ve Erdoğan Sağlam, 2023), bölgedeki balıkçıların %40'ının ürünlerini perakende olarak sattığı (Çalık ve Erdoğan Sağlam, 2015) bildirilmiştir. Mevcut çalışmada balıkçıların %87'ye yakınının günlük 4-6 saat arasında denizde kaldığı, yıl içinde en az 90 gün denize çıkanların oranının %47'ye yakın olduğu, %87'sinin avladıkları balıkları komisyoncular aracılığıyla, kalan %13'lük kısmı ise perakende olarak sattıkları belirlenmiştir.

Köse ve Erdoğan Sağlam (2023), Ordu ilindeki balıkçıların gelir memnuniyeti düzeylerini %61 oranla "iyi", %30 oranla ise "kötü" olarak nitelendirdiklerini ve %76'sının ev sahibi olduğunu bildirmişlerdir. Alıçlı ve ark., (2019), Marmara Ereğlisi küçük ölçekli balıkçıların %52.2'sinin gelirlerinden memnun olduğunu %73.9'unun ev sahibi olduğunu tespit etmişlerdir. Ordu bölgesinde yürütülen bu çalışmada balıkçılıkla uğraşan kişilerin %85.36'sının ev sahibi olduğu; %50'ye yakınının gelir düzeyinden orta seviyede memnun olduğu ve %46'ya yakınının ise gelir memnuniyetlerini kötü olarak nitelendirdikleri belirlenmiştir. Piyasa koşulları, giderlerin artan maliyetleri, dövize endeksli av araç gereçleri gibi nedenlerin balıkçıların gelir durumu memnuniyetsizliğine sebep olabileceği söylenebilir.

Ordu ilinde yapılan çalışmada, bir balıkçılık sezonu içerisinde toplam giderlerin %66.60'ını ağ bakım ve mazot, %20.20'sini tekne bakım, %13,60'ını ise motor bakım giderlerinin oluşturduğu bildirilmiştir (Çalık ve Erdoğan Sağlam, 2015). İstanbul ilinde yapılan çalışmada ise bir teknenin yıllık ortalama 20.888,37 TL akaryakıt harcaması yaptığı ve yağ, tulum, kumanya, nakliye gibi giderler eklendiğinde bu miktarın yıllık ortalama 36.347,73 TL'ye ulaştığı bildirilmiştir (Çiftçi, 2019). Bu çalışmada, küçük ölçekli balıkçılıkla uğraşanların ana gider kalemlerinin akaryakıt, motor yağı, çalışırken giyilen iş elbiseleri ve kumanya olduğu; bakım-onarım, nakliye, hamaliye, aidat, palamar, kumanya, haberleşme, elektrik ve suyun ise diğer giderleri oluşturduğu belirlenmiştir. Tüm bunlar içerisinde, sezon süresince, toplam giderlerin %25.81'lik kısmının ağ bakım ve onarım, %20.65'lik kısmının gemi ve motor bakım onarım, %28.14'lük kısmının mazot ve yağ gideri, kalan %25.80'lik kısmının ise giyim, kumanya, aidat ve harçlardan ibaret olduğu tespit edilmiştir. Tekne bakım onarım masrafları; boya, astar, zehirli boya, macun, badana, zımpara, kızak, çekek işlemi, motor ve pervane bakımından oluşmaktadır. Bu rutin bakım ve onarım işlemlerini barınak ve çekek yerlerinde belirli bir meblağ karşılığında yaptırmak mümkün olsa da küçük ölçekli balıkçılıkla uğraşan bireyler bu bakımları genellikle kendileri yapmaktadırlar. Yukarıda belirtilen giderlere ilave olarak, yıllık ortalama 1.500,00 TL ruhsat, harç, denize elverişlilik belgesi, kırtasiye vb. giderler için; 25.000,00 TL ise avlanma araçları kayıpları için harcandığı bildirilmiştir. Kirlilik, çakışma, gemilerin pervanesine takılma, hava şartlarına bağlı olarak ağın karışması ve yatması, gemilerin ağları kesmesi, ağların üzerine çapa atılması, gel-gitler sularının ağları alması, demire ve taşa takılma, yunusların parçalaması, ilişkene takılma, dibe takılma, gırgır ağlarıyla çakışma, tonoza takılma, dipteki batıklara takılma, dipteki akıntılara kapılma ve yıpranma gibi nedenlerden dolayı ağlarda kayıpların yaşandığı belirlenmiştir. Bölgedeki küçük ölçekli balıkçıların giderlerinin, her ne kadar teknenin boyu, motor gücü, denizde geçirilen gün sayısı, bir seferde denizde kalınan süre ve avcılık yöntemine (algarnayla, ağlarla ve oltayla avcılık) göre değişse de, ortalama kişi başı yıllık 68.100,00 TL ve aylık 5.675,00 TL olduğu tespit edilmiştir.

Araştırmada balıkçıların, avladıkları ürünlerden sağladıkları yıllık ortalama kazanç miktarı 116.241,00 TL olup, aylık 9.686,00 TL olarak belirlenmiş olup, bazı balıkçıların balıkçılık sezonu içinde büyük gırgır teknelerinde çalıştığı ve ek gelir elde ettiği de belirlenmiştir. Yukarıda belirtilen gelir ve giderlere göre aylık net gelirin 4.011,00 TL olduğu görülmektedir. Tarım ve Orman Bakanlığı, küçük ölçekli balıkçılığı desteklemek amacıyla, 12 m'den küçük balıkçı gemilerine destekleme ödemesi yapmaktadır. Bu kapsamda, 2023 yılında, boy uzunluğu; 4.99 metreye kadar olan ruhsatlı balıkçı gemilerine 3.500 TL, 5-7.99 metre arası balıkçı gemilerine 4.250 TL, 8-9.99 metre arası balıkçı gemilerine 5.250 TL, 10-11.99 metre arası denizde avcılık yapan balıkçı gemilerine ise 6.000 TL destekleme ödemesi yapılmıştır (TOB, 2023). Ayrıca 2023 yılında balıkçı gemisinin sahibi veya ortağı olan kadınlara; başvuruda bulunduğu tarihte sahiplik veya ortaklığının devamı halinde, kendisi veya ortakları adına desteklemeye başvuru yapmaları durumunda, balıkçı gemisi başına ödenecek destekleme tutarının %25 fazlası ödenmektedir. Bakanlık tarafından balıkçılara yapılan ortalama destek tutarı da eklendiğinde, balıkçıların aylık ortalama geliri kişi başı 4.395,00 TL'ye yükselmektedir.

5. Sonuç

Sonuç olarak, balıkçıların sosyoekonomik yapıları istenilen düzeyde olmayıp, su ürünleri üretiminin stok yönetiminin daha sağlıklı yapılabilmesi, çevreye duyarlı balıkçılığın gerçekleştirilebilmesi ve küçük ölçekli balıkçılık sektörünün ayakta durabilmesi adına ekonomik koşulların iyileştirilmesi ve yeterli ölçüde nitelikli mesleki eğitime sahip balıkçıların sektöre kazandırılmasına ihtiyaç duyulmaktadır. Tüm bunlar sağlanırsa mevcut kaynaklarımızın daha etkin ve ekonomik kullanımı mümkün olacak ve böylece gelecek nesillere daha sağlıklı su ürünleri tüketim imkanı sunma şansımız olacaktır. Küçük ölçekli balıkçılığın geleceğini garanti altına alabilmek için gereken ilke ve kurallar belirlenerek bunlara uygun yasalar oluşturulmalıdır. Sektörün nasıl yönetilip geliştirileceği konusunda balıkçıların da görüşleri alınarak kararlar verilmeli ve geleceğin balıkçılarına sürdürülebilir bir yönetim anlayışı miras bırakılmalıdır. Tüm bunlar ise eğitim, destek ve tecrübelerin aktarılmasıyla mümkün olacaktır.

6. Etik Standartlara Uygunluk

a) Yazarların katkıları

1. EŞ: Çalışmayı tasarladı, verileri yorumladı, makaleyi hazırladı.
2. NES: Çalışmayı tasarladı, verileri yorumladı, makaleyi hazırladı.
3. SS: Çalışmayı tasarladı, verileri yorumladı, makaleyi hazırladı

Tüm yazarlar son makaleyi okudu ve onayladı

b) Çıkar çatışması
Yazarlar çıkar çatışması olmadığını beyan ettiler.

c) Hayvanların refahına ilişkin beyan
Bu çalışma Deney Hayvanları Yerel Etik Kurul Çalışma protokolünü kapsamamaktadır.

d) İnsan hakları beyanı
Çalışma, Ordu Üniversitesi Sosyal ve Beşeri Bilimler Araştırmaları Etik Kurulu'nun 01/06/2022 tarih ve 2022-116 sayılı kararı ile onaylanmıştır.

Ayrıca bu çalışma, yüksek lisans tezinden üretilmiştir.

7. Kaynakça

Aksu H., Samsun O., Özdemir S. (2023). Karadeniz Kıyılarında Ticari Dip Trol Ağları ile Avlanan Hedef Tür, Hedef Dışı Av ve Iskartanın Birim Çabadaki Av Miktarının (BÇAM) Belirlenmesi. Menba Journal of Fisheries Faculty, 9(2), 27-39. https://doi.org/10.58626/menba.1373906

Alıçlı, Z. T., Doğan, K. & Altunay, M. A. (2019). Marmara Ereğlisi (Tekirdağ) Küçük Ölçekli Balıkçılık Faaliyeti ve Balıkçıların Sosyo-Ekonomik Yapısının Analizi. Aquatic Research, 2(4), 200-210.

Béné, C. (2003). When Fishery Rhymes with Poverty: A First Step Beyond the Old Paradigm on Poverty in Small-scale Fisheries. World development, 31(6), 949-975.

Béné, C., Jeppe, K. & Maarten, B. (2014). Small-scale Fisheries: Importance, Vulnerability and Deficient Knowledge. Governance of Marine Fisheries and Biodiversity Conservation: Interaction and Co-evolution. 317-331.

Berkes, F., Mahon, R. & McConney, P. (2001). Managing Small-scale Fisheries:Alternative Directions and Methods. IDRC (International Development Research Centre).

BSGM, (2023). T.C. Tarım ve Orman Bakanlığı Su Ürünleri İstatistikleri. http://www.tarimorman.gov.tr/BSGM.

Çalık, S., & Erdoğan Sağlam, N. (2015). Ordu İlinde Küçük Ölçekli Balıkçılığın Sosyo-Ekonomik Yapısının Belirlenmesi. Türk Denizcilik ve Deniz Bilimleri Dergisi, 1(2), 107-113.

Çiftçi, M. (2019). İstanbul İli Küçük Ölçekli Balıkçılık Profili Üzerine Bir Araştırma, Fen Bilimleri Enstitüsü, Balıkçılık ve Su Ürünleri İşleme Teknolojisi Anabilim Dalı, İstanbul.

Düz, G. (2011). Bursa ve Kocaeli İlleri Kıyı Balıkçılığının Karşılaştırılmalı Sosyo-Ekonomik Analizi, Fen Bilimleri Enstitüsü, Tarım Ekonomisi Ana Bilim Dalı, Tekirdağ.

Emiçe Saygı, H. (2024). Türkiye'de Balıkçılık ve Su Ürünleri Yetiştiriciliği Sektörünün Mavi Ekonomi Bağlamında Büyüme Beklentileri. Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi, 10 (3), 187-200. DOI: 10.58626/menba.155941

Köse, A. & Erdoğan Sağlam, N. (2023). Ordu İline Kayıtlı Küçük Ölçekli Balıkçı Teknelerinde İş Sağlığı ve Güvenliği, Journal of Anatolian Environmental and Animal Sciences, 8(1), 124-131.

Kurien, J. (1998). Small-scale Fisheries in the Context of Globalisataion, Centre for Development Studies, Thiruvananthapuram.

TOB, (2023). https://www.tarimorman.gov.tr/BSGM/Lists/Duyuru/Attachments/167/ DESTEKLEME.2023. UZATMA%20TAL%C4%B0MATI.pdf

Şahin, S. (2006). Tekirdağ İli Deniz Balıkçılığının Sosyo-Ekonomik Durumu ve Pazarlama Yapısı. Tekirdağ Üniversitesi, Fen Bilimleri Enstitüsü, Y. Lisans Tezi. 97 s.

Uzmanoğlu, S., Soylu, M. (2006). Karasu (Sakarya) Bölgesi Deniz Balıkçılığının Sosyoekonomik Yapısı. Ege Üniversitesi Su Ürünleri Dergisi, 23(1-3), 515-518.

Ünal, V. (2001), Foça Balıkçığının Sosyo-Ekonomik Analizi ve Sürdürülebilirlik Açısından Değerlendirilmesi Üzerine Bir Araştırma, Doktora Tezi, Ege Üniversitesi Fen Bilimleri Enstitüsü.

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

Artificial Intelligence Applications in the Aquaculture Industry: Sustainability, Efficiency and Innovative Solutions

Esen Damla Balo Utku[1], Banu Kutlu[1*]

Abstract: Artificial Intelligence (AI) is becoming increasingly important to increase efficiency and sustainability by organizing processes and providing significant improvements in different sectors. AI is reshaping the aquaculture sector. AI is being used to help solve optimization problems in aquaculture, reduce costs, and find sustainable solutions. These scenarios guided the evaluation of the future role of AI in aquaculture and the benefits that AI brings to the aquaculture sector in this study. AI is improving the way fish stocks are monitored, live stocks are assessed, diseases among plants and animals are recognized, water quality is tested, and production lines are controlled. Aquaculture uses AI technologies to help detect diseases early, monitor environmental conditions affecting production, and improve both efficiency and sustainability. In addition, AI is examining and providing solutions to environmental issues such as global warming and water resource management.

Keywords: Aquaculture, Sustainability, Artificial intelligence

Su Ürünleri Endüstrisinde Yapay Zekâ Uygulamaları: Sürdürülebilirlik, Verimlilik ve Yenilikçi Çözümler

Özet: Yapay Zekâ (YZ), süreçleri organize ederek ve farklı sektörlerde önemli gelişmeler sağlayarak verimliliği ve sürdürülebilirliği artırmak için giderek önemli bir hale gelmektedir. YZ, su ürünleri yetiştiriciliği sektörünü yeniden şekillendirmektedir. YZ, su ürünleri yetiştiriciliğinde optimizasyonla ilgili sorunları çözmeye, maliyetleri düşürmeye ve sürdürülebilir çözümler bulmaya yardımcı olmak için kullanılmaktadır. Bu senaryolar, bu çalışma kapsamında YZ'nın su ürünleri yetiştiriciliğindeki gelecekteki rolünün ve YZ'nın su ürünleri yetiştiriciliği sektörüne sağladığı faydaların değerlendirilmesine rehberlik etmiştir. YZ, balık stoklarının izlenmesi, canlı stokların değerlendirilmesi, bitkiler ve hayvanlar arasındaki hastalıkların tanınması, su kalitesinin test edilmesi ve üretim hatlarının kontrol edilmesi şeklini geliştirmektedir. Hastalıkları erken tespit etmeye, üretimi etkileyen çevre koşullarını izlemeye ve hem verimliliği hem de sürdürülebilirliği iyileştirmeye yardımcı olmak için su ürünleri yetiştiriciliği YZ teknolojilerini kullanmaktadır. Ayrıca, yapay zekâ küresel ısınma ve su kaynaklarının yönetimi gibi çevreyi etkileyen sorunları incelemekte ve bu konulara çözümler sunmaktadır.

Anahtar Kelimeler: Su ürünleri, Sürdürülebilirlik, Yapay zekâ

Article Info (Research)

1 Munzur University, Faculty of Fisheries, Department of Basic Sciences, 62100, Tunceli/Türkiye
***Corresponding Author:**
banukutlu@munzur.edu.tr

Citation: Utku, E.D.B.; Kutlu, B. (2025), Artificial Intelligence Applications in the Aquaculture Industry: Sustainability, Efficiency and Innovative Solutions, MEMBA Water Sciences Journal. 11, (2) 172-181.
https://doi.org/10.58626/memba.1728306

Submission Date: 24 December 2024
Acceptance Date: 03 June 2025
Publishing Date: 28 June 2025

1. Introduction

In today's rapidly evolving technological world, AI is a powerful tool for enhancing processes in various application areas (Rashid et al., 2024). AI is successfully applied in data analysis, prediction, learning, and decision-making tasks by operating the information-processing processes of the human brain (Ahmed et al., 2022). AI has become remarkable in the aquaculture industry because it delivers optimal and creative solutions in numerous application areas that can surpass the disadvantages of conventional techniques.

Artificial intelligence can be defined as the simulation of human intelligence in a machine that can learn, solve problems, reason, make decisions, understand language, and even recognize faces (Zhang and Lu, 2021). Artificial intelligence relativity can learn from data and further utilize this learning in its future trend. AI can arrive at a decision given several inputs by creating recognizable relationships between the pieces of information. With current systems that operate on artificial intelligence, it is possible to incorporate natural language processing technologies. Intelligent systems can convert figures and symbols, such as images and sound, into comprehensible formats for the system's output and are also capable of pattern analysis through the analysis of large data formations (Gupta et al., 2021). For these reasons, artificial intelligence can be considered a crucial technology among others, most notably in industries with data-driven and complex structures, such as aquaculture.

Aquaculture is relied on by an estimated 1 billion people, providing food, livelihoods, and revenues for billions worldwide (Ahmad et al., 2021). For this reason, it calls for sustainable and efficient approaches. However, environmental, economic, and technical factors constrain such progress, hence imposing the need for unique and better technologies. AI offers affordable and practical solutions for the aquaculture industry to enhance the flow of production processes, particularly in light of environmental degradation (Mustapha et al., 2021).

The application of artificial intelligence in aquaculture encompasses population tracking, disease identification in plants and animals, water quality monitoring, and productivity estimation (Gladju et al., 2022). While image processing algorithms identify species using images captured by underwater cameras and drones, deep learning models can help improve production planning by modeling fish growth rates about environmental conditions and enhancing product quality through better resource utilization (Zhao et al., 2025).

Another factor relating the aquaculture industry to sustainability is that the industry relies on natural resources (Engle et al., 2022). AI solutions can be applied for environmental purposes. They can be used to reach objectives such as limiting the fishing industry, ending deforestation, and lowering CO2 emission levels. They can provide economically viable solutions while also having ecological significance (Rodriguez and Costa, 2024).

Diseases are one of the most significant factors affecting the production rate in the aquaculture industry. Islam et al. (2024) reveal that the application of artificial intelligence aids in the diagnosis and control of diseases in fish and other aquaculture species. As with other applications, image processing models input images of fish skin and diagnose infection within record time (Bohara et al., 2024). Given that the process of aquaculture is based on continually evolving environmental and biological indicators, the application of artificial intelligence models studies the impact of certain factors such as water temperature, salinity, and level of dissolved oxygen on production, which, in turn, makes it possible to make appropriate decisions and return production processes to a predictable, designated pattern (Ahmad et al., 2024).

Global warming and climate change are among the most significant risks facing the aquaculture industry. Climate change has become a primary concern for several countries and regions, as evidenced by the increasing use of AI in assessing its impacts (Yadav et al., 2024). Over the years, the impact of climate change on fisheries and aquaculture, as well as methods to mitigate these effects, have been learned from long-term data. However, another benefit that can be obtained from using artificial intelligence in the aquaculture industry is the formation of economic value. The benefits of AI to the industry's commercial advantage include raising efficiency levels in the manufacturing process, increasing output, reducing expenses, and meeting market demand (Mustapha et al., 2021). Unlike previous reviews that focus solely on technical AI advancements or aquaculture systems separately, this study presents an integrated and up-to-date perspective by systematically mapping AI applications in aquaculture with an emphasis on sustainability, climate adaptation, and real-world deployment gaps.

2. Methodology

This article adopts a systematic literature review methodology to explore the applications of AI in the aquaculture industry. Peer-reviewed publications between 2015 and 2025 were retrieved from well-established academic databases, including Scopus, Web of Science, IEEE Xplore, and Google Scholar. The search was conducted using keyword combinations such as artificial intelligence, machine learning, deep learning, aquaculture, fish farming, sustainability, and precision aquaculture. The inclusion criteria were relevance to AI applications in aquaculture, empirical or practical contribution to the field, publication in English, and peer-reviewed status. Studies unrelated to aquatic environments or focusing solely on theoretical AI development were excluded. After removing duplicates and filtering non-relevant papers, 78 articles were selected for detailed review. These articles were categorized into thematic areas, including water quality monitoring, population tracking, disease detection, production optimization, logistics, sustainability, and challenges. The selected works were then critically analyzed in terms of methodological approaches, application levels, and practical relevance to industry needs.

3. Aquaculture

Aquaculture refers to the cultivation of aquatic organisms, including fish, crustaceans, mollusks, and aquatic plants, under controlled conditions (Verdegem et al., 2023). The rapid increase in global population, the decline in terrestrial agricultural areas due to urbanization, and the pressures exerted by hunting on natural fish stocks have led to production that reaches the limits of sustainability through hunting. Aquaculture practices, which can be carried out in both marine and freshwater environments, reduce pressure on natural stocks and contribute to economic development in rural areas. Aquaculture, the fastest-growing sector in the world today, meets a significant portion of the global population's protein needs and is an integral part of sustainable development (Rakkannan and Agarwal, 2025). Aquaculture plays a crucial role in seafood production by providing a sustainable solution to the increasing global food demand. According to FAO 2022 data, global aquaculture production has reached approximately 120 million tons per year, accounting for more than 50% of total aquaculture consumption (Dongyu, 2024). In Turkey, according to the 2023 reports of the Ministry of Agriculture and Forestry, the sector generates export revenues of over $ 1.5 billion, with aquaculture exceeding 500,000 tons per year (Dirican, 2024).

Providing significant contributions in terms of food security, employment, and exports, aquaculture supports the access of approximately 1 billion people worldwide to a basic source of protein (Dewali et al., 2023). Aquaculture projects are emerging as a key component in the development of rural areas and the fight against poverty in developing countries. Developments in the aquaculture sector worldwide have also shown themselves in our country, which is surrounded by seas on three sides (Verdegem et al., 2023). Turkey's geographical location and existing natural resources offer suitable opportunities for fishing and aquaculture. In particular, trout farming in the Black Sea and sea bream-sea bass farming in the Aegean and Mediterranean are the locomotives of the sector. In recent years, new investments, such as shrimp farms in Muğla and Antalya and mussel farms in İzmir, have come to the fore. In inland waters, facilities that produce high-yield trout with closed circuit systems (RAS) are making Turkey progress towards becoming one of the largest aquaculture centers in Europe (Brown et al., 2024).

However, this growth also carries ecosystem risks in the event of uncontrolled expansion. For example, excessive feed use and waste accumulation can hurt water quality. Therefore, biofilter systems and regular water quality monitoring protocols are of vital importance (Pachaiappan et al., 2022). On the other hand, properly planned aquaculture projects can prevent migration by creating employment in rural areas. Sea bream-sea bass farms in Muğla contribute to socio-economic development by providing employment opportunities for thousands of people in the region.

Aquaculture is a rapidly growing sector both globally and in our country. Increasing seawater temperatures due to climate change necessitate a reshaping of aquaculture strategies. Solutions such as orientation towards cold-water species or deep-sea cage systems are on the agenda for adaptation. Within the scope of the EU Green Deal, it is anticipated that facilities with sustainable certification will gain an advantage in exports (Faichuk et al., 2022). The number of ASC (Aquaculture Stewardship Council) certified farms in Turkey is also increasing every year. The issue of why aquaculture is important and its relationship with sustainable development in this context is primarily related to the food problem that is likely to be experienced in the future. The world population is expected to increase to 9.6 billion by 2050, resulting in a substantial demand for food and protein sources (Messina, 2022). Today, fish and fish products provide a significant portion of daily animal protein intake in many developing countries.

Sustainability in aquaculture practices is achieved in line with the goals of reducing environmental impact, protecting biodiversity, and ensuring long-term production efficiency (Troell et al., 2023). Applications such as increasing feed efficiency, reducing antibiotic use, and wastewater treatment are critical for environmentally friendly production. At the same time, certified production systems enhance consumer confidence and promote sustainable production practices. For example, closed-circuit aquaculture systems (RAS) provide up to 90% water savings compared to traditional methods while minimizing environmental impact through effective waste control (Shitu et al., 2022). Thanks to advances in feed technology, the use of insect protein and microalgae instead of fish meal reduces the ecological footprint of the sector.

Production efficiency and animal health are directly dependent on the quality of water. Parameters such as temperature, dissolved oxygen, pH, and ammonia levels are constantly monitored in aquaculture enterprises

(Prapti et al., 2022). In this way, stress factors can be detected early, and intervention can be made possible. Advanced sensor systems and automation technologies have made the production process more controlled and reliable.

4. Applications of Artificial Intelligence in the Aquaculture Industry

Aquaculture is being significantly transformed by AI, which is helping to make farming smarter, more efficient, and more sustainable at different stages. This section provides a step-by-step review of AI applications in aquaculture and the ways AI is helping to modernize the sector.

4.1. Water quality analysis

Using AI, real-time assessments and predictions of key water properties, such as temperature, pH, dissolved oxygen, and ammonia, are possible. The combination of sensors and machine learning enables the detection of anomalies earlier, allowing the system to send signals to the farm manager immediately. This approach reduces the risk of fish kills and promotes quality environments in aquatic systems (Bibri et al., 2024; Capetillo-Contreras et al., 2024). Predicting environmental trends is possible thanks to historical environmental data used to train predictive models that encourage early and positive actions to protect the environment (Grewal et al., 2024; Hanoon et al., 2021). AI systems utilize sensor data collected in real-time to monitor properties such as water clarity, chemical conditions, and nutrient levels in aquaculture farms. Specific patterns become apparent only when ensemble models, such as neural networks or Random Forests, indicate that the input is deviating from the optimal range. Early warning prevents ammonia from harming fish and disturbing the environment.

Additionally, AI systems utilize weather information and water flow data from rivers to detect sudden changes, such as floods or heatwaves. By predicting future needs, facilities can efficiently control filtration, aeration, and water exchange, reducing stress on the ecosystem and energy costs. They contribute to providing accurate and lasting benefits for the aquaculture industry. Most models have been studied so far only in controlled situations and have not been validated in real fish farms.

4.2. Population monitoring and species identification

Using AI, cameras, and drones are used to track fish underwater to determine the species present. Classification systems use the physical characteristics and movements of fish, including their size, color, and movements (Congdon et al., 2022; Alam et al., 2024). Automating this process helps to more accurately assess current stocks, reduce human errors, and protect endangered species (Gebremedhin et al., 2021; Ullah et al., 2024). AI models can recognize species and also show how populations are increasing or decreasing over time. In combination with YOLO and Mask R-CNN, video input is used to calculate the location and biomass of fish in the water. Such technology helps protect various species, control fisheries catches, and manage marine conservation areas.

What is more, they make it possible to monitor fish at all times without disturbing them as much as previous sampling methods. When used in conjunction with geospatial analysis, AI helps identify changes in the way animals move or reproduce in response to environmental changes. While taxonomic identifications are helpful, the approaches depend on the availability of sharp imagery, which can be challenging to obtain in some waters.

4.3. Disease detection and management

Catching diseases early is crucial in aquaculture. AI models look at images and movement patterns to detect health problems early and help stop their spread. In recent studies (Bohara et al., 2024; Hatzilygeroudis et al., 2023; Kumar et al., 2024), variables such as temperature, the number of people living in a place, and water quality can be used in conjunction with deep learning algorithms to predict outbreaks. CNNs are used in advanced systems to identify visual signs of disease from fish images very accurately. Sometimes, AI trained on large sets of infected and healthy fish performs faster and moves more smoothly than human diagnosticians. Using these resources helps lead to early intervention, stop losses, and reduce medication use. The ability to look at behavior and conditions could allow AI to identify hidden stress or risk of early infection by identifying nutritional deficiencies, unusual movements, or increased gill ventilation. Combined with genomic or microbial testing, such data could lead to better healthcare. It is often tricky for AI models to be portable across species and locations because the data available today is not well organized or diverse enough.

4.4. Optimization of production processes

AI utilizes models to determine the optimal times to harvest and feed fish based on genetic, environmental, and nutritional history information. Thanks to these models, feeding systems use less food, waste is reduced, and the products produced are of higher quality. In other words, AI can detect slow growth caused by insufficient feed and suggest steps to solve the problem (Zhang et al., 2023; Mandal and Ghosh, 2024; Capetillo-Contreras et al., 2024; Nagothu et al., 2025). AI utilizes various information, including temperature, stocking density, feed composition, and lighting cycles, to advise users on the optimal daily actions for achieving better biomass results. More often, reinforcement learning is used to mimic feeding practices and predict outcomes over time. With this approach, producers reduce their environmental impact by wasting less feed and minimizing energy and nutrient discharge. With Aquaculture Insights, precision farming becomes possible by adjusting resources according to the fish's current needs. Although optimization models have yielded positive results, very few of them are used in commercial software used by fish farmers.

4.5. Supply chain and logistics optimization

AI assists in supply chain tasks by providing more accurate demand forecasting, optimizing routes, and managing cold zones in logistics. Using machine learning, past sales, and seasonal trends are examined to predict future sales, which helps the business avoid excessive stock losses (Elufioye et al., 2024; Galaz et al., 2021). To guarantee good transport conditions for the animals and their products, AI watches over water temperature and oxygen levels during live fish delivery (Pajic et al., 2024; Anwar et al., 2023; Sohail et al., 2018). Through IoT devices, real-time monitoring of logistics conditions is easier with the aid of AI. Experience tells us that monitoring dissolved oxygen, water salinity, and vibration helps detect any potentially hazardous changes before they can harm the livestock. In addition, using AI and blockchain makes it possible to trace the entire process the fish undergoes, from where it is farmed to when it is sold. Thus, the situation helps the company meet regulations and identify any issues or risks associated with its distribution of goods. Nonetheless, large-scale, go-live applications are still necessary to truly demonstrate the effectiveness of such approaches in various logistics scenarios.

4.6. Sustainability and adaptation to climate change

AI is helping to protect the environment by identifying the effects of climate change on water. It forecasts changes in water temperature, salt levels, and acidity and suggests when and how fish will migrate and reproduce. Applying these findings facilitates the design of adaptive strategies and reduces the CO2 footprint from aquaculture, thereby helping aquaculture align with global climate goals (Goodwin et al., 2022; Mugwanya et al., 2022; Parab et al., 2023; Ditria et al., 2022; Fu et al., 2024). Simulations using artificial intelligence can help study how climate change impacts marine life and support the development of farming methods that are more resilient to climate change. In some cases, ensemble models display simulations of new habitats and suggest suitable areas to grow various crops. When combined with environmental devices, AI enables the monitoring of carbon emissions, enhances waste disposal, and assesses the impact of a business on the environment. Such knowledge supports the creation of sustainable certification programs that align with global rules, such as the EU Green Deal. Despite progress in climate modeling using AI, very few works connect the predictions from AI with real actions in the aquaculture industry.

4.7. Industry-specific challenges and opportunities

Although there are benefits, the use of AI in aquaculture is limited by high costs, inadequate facilities, and insufficient digital training for those involved. The field of agriculture is exploring new ways to utilize automation, precision farming, and enhance decision-making (Mustapha et al., 2021; Engle et al., 2022). A challenge in adoption is that hardware systems do not use consistent data formats for integration. A significant number of aquaculture businesses lack the expertise to handle the results generated by AI or operate sophisticated computer systems. Due to these challenges, interfaces and training courses should be designed in a manner that allows everyone to follow them. The use of low-cost sensors and cloud-based analytics is making it easier for more people to utilize AI. Together with universities and startups working in agri-tech, the firms have improved and accelerated solutions that take into account regional species, weather, and infrastructure. Additionally, very few solutions exist just for smallholder farmers in resource-poor areas.

4.8. Advantages and limitations of AI applications

AI enables high accuracy and instant analysis, reducing potential human errors. Artificial intelligence can enable businesses to make faster decisions and improve resource utilization (Zhang and Lu, 2021; Gupta et al., 2021). How explainable our models are is still a critical consideration. Although deep learning models can predict results with great accuracy, their complex results often cause users to doubt the decisions. Now, regulatory agencies are demanding greater transparency from companies, particularly in AI decisions involving animals or environmental safety. Some parts of the world suffer from a lack of data because the sensor network infrastructure is not fully complete. Although transfer learning and generating synthetic data are promising, they require further study and validation. Many studies suffer from using models that are difficult to explain, which leads to concerns about applying them in practice.

4.9. Future research directions

Future research in AI-aided aquaculture should focus on explainable AI (XAI), federated learning for data privacy, the integration of multimodal datasets (e.g., sensor, image, genomic), and the development of hybrid models. Additionally, affordability, accessibility, and user-friendly interfaces should be prioritized to facilitate adoption among smallholder farmers and in developing regions (Ullah et al., 2024; Rashid and Kausik, 2024). Moreover, interdisciplinary collaboration is crucial for bridging the gaps between aquaculture experts, data scientists, and policymakers. Research into the ethical implications, data ownership, and ecological impact assessments will become increasingly important as AI systems assume more autonomous roles in the industry. Pilot projects and case studies documenting real-world deployments of AI systems in aquaculture, particularly in diverse geographical contexts, are also necessary to inform best practices, policy, and investment decisions in the sector. While many future directions are proposed, a lack of interdisciplinary collaboration often hinders practical innovation and field application.

5. Practical Recommendations for the Aquaculture Industry

Based on the reviewed literature, several actionable recommendations can be proposed to guide the practical integration of AI technologies in the aquaculture sector. Start with scalable, low-cost AI solutions such as feed optimization and water quality sensors to lower entry barriers, especially for small and medium-scale farms. Invest in training and digital literacy programs to empower aquaculture professionals to effectively understand, deploy, and maintain AI systems. Public-private partnerships should be encouraged to test real AI projects and create useful use cases. Data-sharing standards should be established to support the development of higher-quality datasets, enabling the creation of reliable models for various tasks. XAI research should be continued to ensure that decisions made by models can be understood and used by those who manage the industry. Aquaculture worldwide benefits from better sustainability, improved efficiency, and increased resilience. Therefore, authorities and regulators should be involved in establishing clear guidelines for the ethical use of AI technologies in aquaculture. Such frameworks should address issues such as data ownership, accountability for decisions made by machines, and the security of personal data related to farming. At the same time, tax breaks, grants, and subsidized AI options can encourage more regions to adopt AI, especially in developing countries. Another important aspect is the involvement of fishery stakeholders, such as fish farmers, technicians, and aquaculture engineers, in the design and development of AI tools. Involving stakeholders during design and testing ensures that AI applications will reflect their needs, making them subsequently reliable and usable. For AI to be used globally, interfaces need to be in different languages , and examples need to be localized. As time passes, the use of cloud and real-time AI systems can help farmers utilize predictive technology, remotely monitor operations, and automatically control various tasks. Deciding on innovative aquaculture ecosystems will depend on robust cyber-physical systems that incorporate IoT and data security systems. Academic, industry, and policy organizations must collaborate to establish the appropriate digital infrastructure and management systems. The ethical and environmental dimensions of AI integration must not be overlooked. AI should be leveraged to support biodiversity conservation, minimize resource overuse, and reduce environmental externalities such as water pollution and carbon emissions. Models that incorporate multi-objective optimization balancing economic yield with ecological impact will be crucial in aligning aquaculture practices with the principles of sustainable development.

6. Conclusion

In this paper, five AI technologies namely machine learning, deep learning, image processing, sensor-based decision systems, and predictive analytics were reviewed in terms of their functionality in aquaculture, and the benefits of their application were discussed. The benefits of artificial intelligence include improved productivity and decreased costs, as long as the new areas for doing business and the enhancement of the innovation environment contribute to the economic development of the aquaculture business. The use of artificial intelligence in the aquaculture industry relates to the economic impact, environmental gains, and conservation.

AI is used in aquaculture to track fish, diagnose fish diseases, examine water quality, enhance production, and efficiently utilize resources and sustainability. Underwater captured images are analyzed by artificial intelligence to determine the type of fish and population growth. As a result of using image processing algorithms, one obtains fast and accurate results, reducing the number of mistakes made by humans, thus solving problems related to the environment, such as overfishing and destroying habitats, and promoting sustainability. AI can be used in the early detection of diseases affecting fish and aquatic plants, helping to minimize potential production losses and improve the overall health of aquatic organisms.

By studying how environmental conditions influence fish growth, AI can inform operations and enhance fish production. For example, sensors utilizing AI predictive models can quickly indicate whether water temperature, oxygen, or salinity levels are correct, allowing production lines to run smoothly. Smart techniques help minimize any environmental burden in the aquaculture market. Thanks to AI, fishing now has a significantly reduced impact on the planet and the fish population. This technology is crucial for detecting and mitigating climate change and temperature fluctuations in water.

For practitioners in the aquaculture industry, this study highlights several actionable lessons. The implementation of low-cost AI tools such as real-time water quality monitoring, early disease detection, and predictive feeding systems can significantly improve efficiency and reduce operational costs. Moreover, integrating explainable AI models and developing user-friendly interfaces are essential to foster trust and adoption, especially in small to mid-scale farms. Collaborations with tech developers and academic institutions can accelerate the deployment of AI systems tailored to regional and species-specific needs.

In the context of Türkiye, future studies can explore the development and deployment of region-specific AI models tailored to species such as sea bream, sea bass, and trout, which dominate the country's aquaculture industry, with a focus on local environmental conditions and infrastructure capacities.

7. Compliance with Ethical Standard

a) Author Contributions

1. E.D.B.U.: Conceptualization, methodology, software development, validation, formal analysis, investigation, resource collection, writing—original draft preparation, writing—review and editing.
2. B.K.: Conceptualization, methodology, supervision, validation, formal analysis, data curation, writing—review and editing, visualization.

b) Conflict of Interests

There is no conflict of interest, according to the authors.

c) Statement on the Welfare of Animals

Not relevant

d) Statement of Human Rights

There are no human subjects in this study.

e) Funding

This study was supported by

f) Artificial Intelligence Statement

During the preparation of this manuscript, the authors utilized artificial intelligence-based tools for language refinement, grammar correction, and assistance in improving the clarity and fluency of the text. All intellectual content, ideas, data interpretation, and critical insights were developed and finalized by the authors themselves. The AI tools did not contribute to scientific reasoning or experimental design.

8. References

Ahmad, A., Abdullah, S. R. S., Hasan, H. A., Othman, A. R., & Ismail, N. I. (2021). Aquaculture industry: Supply and demand, best practices, effluent and its current issues and treatment technology. Journal of Environmental Management, 287, 112271.

Ahmad, T., Ali, L., Alshamsi, D., Aldahan, A., El-Askary, H., & Ahmed, A. (2024). AI-Powered Water Quality Index Prediction: Unveiling Machine Learning Precision in Hyper-Arid Regions. Earth Systems and Environment, 1-18.

Ahmed, I., Jeon, G., & Piccialli, F. (2022). From artificial intelligence to explainable artificial intelligence in industry 4.0: a survey on what, how, and where. IEEE Transactions on Industrial Informatics, 18(8): 5031-

5042.
Alam, M., Khan, I. R., Siddiqui, F., & Alam, M. A. (2024). Artificial Intelligence as Key Enabler for Safeguarding the Marine Resources. In Artificial Intelligence and Edge Computing for Sustainable Ocean Health, 409-451.
Anwar, H., Anwar, T., & Mahmood, G. (2023). Nourishing the Future: AI-Driven Optimization of Farm-to-Consumer Food Supply Chain for Enhanced Business Performance. Innovative Computing Review, 3(2).
Aragonés Lozano, M., Pérez Llopis, I., & Esteve Domingo, M. (2023). Threat hunting architecture using a machine learning approach for critical infrastructures protection. Big data and cognitive computing, 7(2).
Bibri, S. E., Krogstie, J., Kaboli, A., & Alahi, A. (2024). Smarter eco-cities and their leading-edge artificial intelligence of things solutions for environmental sustainability: A comprehensive systematic review. Environmental Science and Ecotechnology, 19, 100330.
Bohara, K., Joshi, P., Acharya, K. P., & Ramena, G. (2024). Emerging technologies revolutionising disease diagnosis and monitoring in aquatic animal health. Reviews in Aquaculture, 16(2): 836-854.
Brown, A. R., Wilson, R. W., & Tyler, C. R. (2024). Assessing the Benefits and Challenges of Recirculating Aquaculture Systems (RAS) for Atlantic Salmon Production. Reviews in Fisheries Science & Aquaculture, 1-22.
Capetillo-Contreras, O., Pérez-Reynoso, F. D., Zamora-Antuñano, M. A., Álvarez-Alvarado, J. M., & Rodríguez-Reséndiz, J. (2024). Artificial intelligence-based aquaculture system for optimizing the quality of water: A systematic analysis. Journal of Marine Science and Engineering, 12(1).
Congdon, J. V., Hosseini, M., Gading, E. F., Masousi, M., Franke, M., & MacDonald, S. E. (2022). The future of artificial intelligence in monitoring animal identification, health, and behaviour. Animals, 12(13).
Cooke, S. J., Auld, H. L., Birnie-Gauvin, K., Elvidge, C. K., Piczak, M. L., Twardek, W. M., & Muir, A. M. (2023). On the relevance of animal behavior to the management and conservation of fishes and fisheries. Environmental Biology of Fishes, 106(5): 785-810.
Dewali, S., Sharma, N., Melkani, D., Arya, M., Kathayat, N., Panda, A. K., & Bisht, S. S. (2023). Aquaculture: Contributions to global food security. In Emerging solutions in sustainable food and nutrition security (pp. 123-139). Cham: Springer International Publishing.
Dirican, S. (2024). Current Status of Floating Net Cages Aquaculture in Sivas Province (Turkey). Asian Journal of Applied Science and Technology (AJAST), 8(4), 01-11.
Ditria, E. M., Buelow, C. A., Gonzalez-Rivero, M., & Connolly, R. M. (2022). Artificial intelligence and automated monitoring for assisting conservation of marine ecosystems: A perspective. Frontiers in Marine Science, 9.
Dongyu, Q. (2024). 2024 THE STATE OF WORLD FISHERIES AND AQUACULTURE-BLUE TRANSFORMATION IN ACTION. The State of World Fisheries and Aquaculture, R1-232.
Elufioye, O. A., Ike, C. U., Odeyemi, O., Usman, F. O., & Mhlongo, N. Z. (2024). Ai-Driven predictive analytics in agricultural supply chains: a review: assessing the benefits and challenges of ai in forecasting demand and optimizing supply in agriculture. Computer Science & IT Research Journal, 5(2): 473-497.
Engle, C. R., & van Senten, J. (2022). Resilience of communities and sustainable aquaculture: governance and regulatory effects. Fishes, 7(5).
Faichuk, O., Voliak, L., Hutsol, T., Glowacki, S., Pantsyr, Y., Slobodian, S., & Gródek-Szostak, Z. (2022). European Green Deal: Threats Assessment for Agri-Food Exporting Countries to the EU. Sustainability, 14(7), 3712.
Fu, X., Zhang, C., Chang, F., Han, L., Zhao, X., Wang, Z., & Ma, Q. (2024). Simulation and forecasting of fishery weather based on statistical machine learning. Information Processing in Agriculture, 11(1), 127-142.servation of marine ecosystems: A perspective. Frontiers in Marine Science, 9.
Galaz, V., Centeno, M. A., Callahan, P. W., Causevic, A., Patterson, T., Brass, I., & Levy, K. (2021). Artificial intelligence, systemic risks, and sustainability. Technology in Society, 67.
Gambín, Á. F., Angelats, E., González, J. S., Miozzo, M., & Dini, P. (2021). Sustainable marine ecosystems: Deep learning for water quality assessment and forecasting. IEEE access, 9: 121344-121365.
Gebremedhin, S., Bruneel, S., Getahun, A., Anteneh, W., & Goethals, P. (2021). Scientific methods to understand fish population dynamics and support sustainable fisheries management. Water, 13(4).
Gladju, J., Kamalam, B. S., & Kanagaraj, A. (2022). Applications of data mining and machine learning framework in aquaculture and fisheries: A review. Smart Agricultural Technology, 2(100061).
Goodwin, M., Halvorsen, K. T., Jiao, L., Knausgård, K. M., Martin, A. H., Moyano, M., ... & Thorbjørnsen, S. H. (2022). Unlocking the potential of deep learning for marine ecology: overview, applications, and outlook. ICES Journal of Marine Science, 79(2): 319-336.
Grewal, D., Guha, A., Noble, S. M., & Bentley, K. (2024). The food production–consumption chain: Fighting food insecurity, loss, and waste with technology. Journal of the Academy of Marketing Science, 52(5): 1412-1430.
Gupta, R., Srivastava, D., Sahu, M., Tiwari, S., Ambasta, R. K., & Kumar, P. (2021). Artificial intelligence

to deep learning: machine intelligence approach for drug discovery. Molecular diversity, 25: 1315-1360.
Hanoon, M. S., Ahmed, A. N., Fai, C. M., Birima, A. H., Razzaq, A., Sherif, M., & El-Shafie, A. (2021). Application of artificial intelligence models for modeling water quality in groundwater: comprehensive review, evaluation and future trends. Water, Air, & Soil Pollution, 232: 1-41.
Hatzilygeroudis, I., Dimitropoulos, K., Kovas, K., & Theodorou, J. A. (2023). Expert Systems for Farmed Fish Disease Diagnosis: An Overview and a Proposal. Journal of Marine Science and Engineering, 11(5).
Honarmand Ebrahimi, S., Ossewaarde, M., & Need, A. (2021). Smart fishery: a systematic review and research agenda for sustainable fisheries in the age of AI. Sustainability, 13(11).
Islam, S. I., Ahammad, F., & Mohammed, H. (2024). Cutting-edge technologies for detecting and controlling fish diseases: Current status, outlook, and challenges. Journal of the World Aquaculture Society, 55(2).
Krishnan, S. R., Nallakaruppan, M. K., Chengoden, R., Koppu, S., Iyapparaja, M., Sadhasivam, J., & Sethuraman, S. (2022). Smart water resource management using Artificial Intelligence—A review. Sustainability, 14(20).
Kumar, S., Srivastava, A., & Maity, R. (2024). Modeling climate change impacts on vector-borne disease using machine learning models: Case study of Visceral leishmaniasis (Kala-azar) from Indian state of Bihar. Expert Systems with Applications, 237(121490).
Mandal, A., & Ghosh, A. R. (2024). Role of artificial intelligence (AI) in fish growth and health status monitoring: A review on sustainable aquaculture. Aquaculture International, 32(3): 2791-2820.
Messina, M. (2022). Perspective: Soybeans can help address the caloric and protein needs of a growing global population. Frontiers in nutrition, 9, 909464.
Mohale, H. P., Narsale, S. A., Kadam, R. V., Prakash, P., Sheikh, S., Mansukhbhai, C. R., & Baraiya, R. (2024). Artificial Intelligence in Fisheries and Aquaculture: Enhancing Sustainability and Productivity. Archives of Current Research International, 24(3): 106-123.
Mugwanya, M., Dawood, M. A., Kimera, F., & Sewilam, H. (2022). Anthropogenic temperature fluctuations and their effect on aquaculture: A comprehensive review. Aquaculture and Fisheries, 7(3): 223-243.
Mustapha, U. F., Alhassan, A. W., Jiang, D. N., & Li, G. L. (2021). Sustainable aquaculture development: a review on the roles of cloud computing, internet of things and artificial intelligence (CIA). Reviews in Aquaculture, 13(4): 2076-2091.
Nagothu, S. K., Bindu Sri, P., Anitha, G., Vincent, S., & Kumar, O. P. (2025). Advancing aquaculture: fuzzy logic-based water quality monitoring and maintenance system for precision aquaculture. Aquaculture International, 33(1).
Pachaiappan, R., Cornejo-Ponce, L., Rajendran, R., Manavalan, K., Femilaa Rajan, V., & Awad, F. (2022). A review on biofiltration techniques: recent advancements in the removal of volatile organic compounds and heavy metals in the treatment of polluted water. Bioengineered, 13(4), 8432-8477.
Pajic, V., Andrejic, M., & Chatterjee, P. (2024). Enhancing cold chain logistics: A framework for advanced temperature monitoring in transportation and storage. Mechatron. Intell Transp. Syst, 3(1): 16-30.
Parab, V., Prajapati, J. J., Karan, S., Bhowmick, A. R., & Mukherjee, J. (2023). Impact of abiotic factors and heavy metals in predicting the population decline of Near Threatened fish Notopterus chitala in natural habitat. Aquatic Ecology, 57(4): 863-879.
Piñeros, V. J., Reveles-Espinoza, A. M., & Monroy, J. A. (2024). From Remote Sensing to Artificial Intelligence in Coral Reef Monitoring. Machines, 12(10).
Prapti, D. R., Mohamed Shariff, A. R., Che Man, H., Ramli, N. M., Perumal, T., & Shariff, M. (2022). Internet of Things (IoT)-based aquaculture: An overview of IoT application on water quality monitoring. Reviews in Aquaculture, 14(2), 979-992.
Rakkannan, G., & Agarwal, D. (2025). Role of Aquaculture Biotechnology in Food Security and Nutrition. In Food Security, Nutrition and Sustainability Through Aquaculture Technologies (pp. 173-191). Cham: Springer Nature Switzerland.
Rashid, A. B., & Kausik, A. K. (2024). AI revolutionizing industries worldwide: A comprehensive overview of its diverse applications. Hybrid Advances, 100277.
Rodriguez, P., & Costa, I. (2024). Exploring the Role of AI in Sustainable Development and Environmental Monitoring. MZ Computing Journal, 5(1).
Shitu, A., Liu, G., Muhammad, A. I., Zhang, Y., Tadda, M. A., Qi, W., & Zhu, S. (2022). Recent advances in application of moving bed bioreactors for wastewater treatment from recirculating aquaculture systems: A review. Aquaculture and Fisheries, 7(3), 244-258.
Sohail, M., Sun, D. W., & Zhu, Z. (2018). Recent developments in intelligent packaging for enhancing food quality and safety. Critical reviews in food science and nutrition, 58(15): 2650-2662.
Troell, M., Costa-Pierce, B., Stead, S., Cottrell, R. S., Brugere, C., Farmery, A. K., & Barg, U. (2023). Perspectives on aquaculture's contribution to the Sustainable Development Goals for improved human and

planetary health. Journal of the World Aquaculture Society, 54(2), 251-342.

Tynchenko, V., Kukartseva, O., Tynchenko, Y., Kukartsev, V., Panfilova, T., Kravtsov, K., ... & Malashin, I. (2024). Predicting Tilapia Productivity in Geothermal Ponds: A Genetic Algorithm Approach for Sustainable Aquaculture Practices. Sustainability, 16(21).

Ullah, F., Saqib, S., & Xiong, Y. C. (2024). Integrating artificial intelligence in biodiversity conservation: bridging classical and modern approaches. Biodiversity and Conservation, 1-21.

Verdegem, M., Buschmann, A. H., Latt, U. W., Dalsgaard, A. J., & Lovatelli, A. (2023). The contribution of aquaculture systems to global aquaculture production. Journal of the World Aquaculture Society, 54(2), 206-250.

Yadav, N. K., Patel, A. B., Singh, S. K., Mehta, N. K., Anand, V., Lal, J., ... & Devi, N. C. (2024). Climate change effects on aquaculture production and its sustainable management through climate-resilient adaptation strategies: a review. Environmental Science and Pollution Research, 1-21.

Zhang, R., Chen, T., Wang, Y., & Short, M. (2023). Systems approaches for sustainable fisheries: A comprehensive review and future perspectives. Sustainable production and consumption.

Zhao, Y., Qin, H., Xu, L., Yu, H., & Chen, Y. (2025). A review of deep learning-based stereo vision techniques for phenotype feature and behavioral analysis of fish in aquaculture. Artificial Intelligence Review, 58(1): 1-61.

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

Phage Therapy in Aquaculture: Applications, Efficacy and Challenges

Mustafa Üstündağ[1*]

Abstract: Aquaculture and fisheries have emerged as some of the fastest-growing food sectors in recent years. However, the indiscriminate use of antibiotics in aquaculture and fisheries has led to the development and spread of antibiotic resistance. In this context, phage therapy offers an alternative, sustainable, and environmentally friendly solution for controlling pathogens that cause significant economic losses in aquaculture. Over recent years, the application of phage therapy in aquaculture has gained increasing attention. Phage therapy has shown promising results in controlling pathogens such as Vibrio, Aeromonas, and Flavobacterium. This method effectively improves fish health, reduces antibiotic usage, and preserves microbial balance due to the specificity of phages. Despite its potential, several challenges affect the efficacy and success of phage therapy. These challenges include the sensitivity of phages to environmental factors, the potential of bacteria to develop resistance against phages, difficulties in developing effective phage formulations, and scientific gaps in phage therapy research. To address these issues, biotechnological and nanotechnological methods have been employed to enhance the effectiveness of phages and increase their resilience to environmental factors. Innovative technologies such as CRISPR-Cas9 enhance the specificity of phages toward target pathogens while supporting microbial balance. Additionally, microencapsulation techniques strengthen phage stability, enabling more efficient application. However, for the large-scale implementation of phage therapy, clear regulatory frameworks and economic sustainability are required. This study provides a comprehensive evaluation of the applications and efficacy of phages, advanced techniques used in their formulation, challenges encountered in phage therapy, and existing scientific gaps in the field of aquaculture. The insights gained from this study are expected to contribute significantly to the expansion of phage therapy applications in aquaculture, raise awareness about reducing antibiotic use, and support sustainable production practices.

Keywords: Aquaculture, bacteriophages, antibiotics, resistance

Kültür Balıkçılığında Faj Terapisi Uygulamaları ve Karşılaşılan Zorluklar

Özet: Kültür balıkçılığı ve su ürünleri yetiştiriciliği son yıllarda en hızlı büyüyen gıda sektörlerinden biridir. Ancak, kültür balıkçılığı ve su ürünleri yetiştiriciliğinde antibiyotiklerin bilinçsiz kullanımı, antibiyotik direncinin gelişimine ve yayılmasına neden olmaktadır. Bu bağlamda, faj terapisi kültür balıkçılığında ekonomik kayıplara yol açan patojenlerin kontrol altına alınmasında alternatif, sürdürülebilir ve çevre dostu bir çözüm sunmaktadır. Kültür balıkçılığında faj terapisi uygulamaları, son yıllarda giderek yaygınlaşmaktadır. Faj terapisi, *Vibrio, Aeromonas* ve *Flavobacterium* gibi patojenlerin kontrol altına alınmasında umut vadeden sonuçlar göstermiştir. Bu yöntem, balık sağlığının iyileştirilmesi, antibiyotik kullanımının azaltılması ve fajların özgüllüğü sayesinde mikrobiyal dengenin korunması açısından etkili olabilmektedir. Ancak, fajların çevresel faktörlere duyarlılığı, bakterilerin fajlara direnç geliştirme potansiyeli, etkin faj formülasyonlarının oluşturulmasındaki güçlükler ve faj terapisindeki bilimsel eksiklikler, bu yöntemin etkinliği ve başarısını etkileyen önemli zorluklardır. Bu çözüm bekleyen konulardan, fajların etkinliğini artırılması ve çevresel faktörlere karşı dayanıklılığının sağlaması amacıyla biyoteknolojik ve nanoteknolojik yöntemlerden yararlanılmaktadır. CRISPR-Cas9 gibi yenilikçi teknolojiler, fajların hedef patojenlere olan spesifikliğini artırarak mikrobiyal dengeyi desteklemekte, mikroenkapsülasyon yöntemleri ise fajların stabilitesini güçlendirmektedir. Bununla birlikte, faj terapisinin geniş ölçekte uygulanabilirliğini sağlamak için yasal düzenlemelerin oluşturulması ve ekonomik sürdürülebilirliğin sağlanması gereklidir. Bu çalışmada, kültür balıkçılığında hastalıkların kontrol altına alınmasında ve çevre dostu, sürdürülebilir üretim uygulamalarında önemli potansiyele sahip olan fajların uygulamaları, etkinlikleri, formülasyonlarında kullanılan ileri düzey teknikler, faj terapisinde karşılaşılan zorluklar ve bilimsel eksiklikler ayrıntılı bir şekilde değerlendirilmiştir. Elde edilen bilgilerin, kültür balıkçılığında faj terapisi uygulamalarının artmasına, bu alanda farkındalık yaratarak antibiyotik kullanımının azalmasına ve sürdürülebilir üretimin sağlanmasına önemli katkılar sağlayacağı düşünülmektedir.

Anahtar Kelimeler: Kültür balıkçılığı, bakteriyofaj, antibiyotik, direnç

Article Info (Review)

1 Van Yuzuncu Yil University, Zeve Campus, 65080, Van/Türkiye
***Corresponding Author:**
m.ustundg@gmail.com

Citation: Üstündağ, M. (2025), Phage Therapy in Aquaculture: Applications, Efficacy and Challenges MEMBA Water Sciences Journal. 11, (2) 182-200.
https://doi.org/10.58626/memba.1728310

Submission Date: 19 January 2025
Acceptance Date: 19 June 2025
Publishing Date: 28 June 2025

1. Introduction

In recent years, factors such as rapid population growth, insufficient livestock and agricultural production, and inefficient use of natural resources have driven an increasing demand for food (Pereira et al., 2022). Many countries today face critical challenges, including the need for alternative food sources, sustainable food management, and high-quality protein production. In this context, aquaculture and fisheries, as the fastest-growing food sectors in recent years, present a significant opportunity. According to reports by the Food and Agriculture Organization (FAO), global fish production has increased dramatically from 3 million tons in the 1970s to 178.5 million tons in 2018 (Rocha et al., 2022).

The importance of aquaculture and fisheries in meeting the rising demand for food sustainably has grown significantly. Consequently, various aquaculture systems have been developed, with intensive production systems being widely adopted worldwide. While intensive systems aim to maximize yield per unit area, factors such as high stocking densities, improper feeding practices, and adverse environmental conditions contribute to water quality deterioration. These conditions increase the prevalence of bacterial, viral, fungal, and parasitic fish diseases (Dang et al., 2021).

The widespread occurrence of diseases in aquaculture, coupled with the indiscriminate use of antibiotics, negatively affects production performance and leads to economic losses. The excessive use of antibiotics promotes the dissemination of resistant genes within aquatic ecosystems, disrupting microbial balance and accelerating the proliferation of resistant bacteria (Kunttu et al., 2021; Liang et al., 2023). Antibiotic resistance has become a global concern in aquaculture. This resistance spreads rapidly among aquatic bacteria through genetic and biochemical pathways, threatening microbial balance and posing serious risks to human health (Ye et al., 2019; Sundberg et al., 2021). These challenges underscore the necessity for environmentally friendly and practical solutions in aquaculture.

Bacteriophages (phages) represent a promising therapeutic option. These viruses naturally target bacteria with high specificity, aiding in the preservation of microbial balance (Imbeault et al., 2006). Phages have shown efficacy against common aquaculture pathogens such as *Vibrio, Aeromonas*, and *Flavobacterium*, offering hope for disease control and the reduction of antibiotic use (Dang et al., 2021).

Recent research on phage therapy has advanced the practical application of these agents in aquaculture. Phage therapy is now recognized as an effective and environmentally sustainable treatment option in the field. This study focuses on the applications of bacteriophages in aquaculture, evaluating their impacts, benefits, and the challenges encountered during implementation.

2. Antibiotic Resistance in Aquaculture

Antibiotic resistance has emerged as an escalating threat not only in aquaculture but also across the entire ecosystem. The indiscriminate use of antibiotics in aquaculture and fisheries significantly accelerates the development and spread of antibiotic-resistant bacteria within aquatic environments. Today, many pathogens in aquaculture are reported to have developed resistance to one or more antibiotics (Pereira et al., 2022; Liang et al., 2023). Moreover, such misuse does not only induce resistance in target pathogens but also disrupts aquatic ecosystems and microbiota, causing broader ecological harm (Zhang et al., 2021).

For instance, oxytetracycline, recognized as a broad-spectrum antimicrobial agent, is widely used in aquaculture. Pathogens such as *Aeromonas salmonicida* have been reported to develop resistance to oxytetracycline and florfenicol; *Aeromonas hydrophila* to oxytetracycline, ampicillin, amoxicillin, and florfenicol; *Yersinia ruckeri* to oxytetracycline and florfenicol; *Flavobacterium columnare* to oxytetracycline; *E. tarda* to florfenicol; and *Streptococcus iniae* to sulfonamides (Scarano et al., 2018; Zhang et al., 2021; Feng et al., 2022).

Similar patterns are observed in marine fish pathogens. Prominent species, including *Vibrio parahaemolyticus, Photobacterium damselae subsp. piscicida, Tenacibaculum maritimum,* and *E. tarda*, have shown resistance to oxytetracycline. Furthermore, species such as *Vibrio, Edwardsiella*, and *Photobacterium* have exhibited resistance to florfenicol, amoxicillin, ampicillin, and oxolinic acid (Kusunur et al., 2023).

Studies conducted in Turkey in 2025 have demonstrated that aquatic isolates of *Aeromonas hydrophila* exhibit high levels of resistance to tetracyclines (doxycycline) and aminoglycosides (gentamicin) (Türe and Alp, 2016). Likewise, *Pseudomonas fluorescens* strains display widespread resistance to sulfonamides (trimethoprim–sulfamethoxazole) and β-lactams (cephalothin), and have also acquired resistance to chloramphenicol (Yılmaz and Berik, 2025). In addition, seawater–derived *Aeromonas molluscorum* isolates show reduced susceptibility to erythromycin, while *Staphylococcus haemolyticus* strains manifest phenotypic resistance to fluoroquinolones (ciprofloxacin) and glycopeptides (vancomycin) (Baytaroglu and Kucukkagnici, 2025). These data underscore the pervasive nature of antibiotic resistance among aquatic pathogens in Turkey and highlight the critical importance of phage–antibiotic combination strategies in addressing resistant infections.

In addition, certain bacterial strains in aquaculture have developed resistance to multiple antibiotics, a condition termed "multi-drug resistance," which severely limits treatment options (Kusunur et al., 2023).

Addressing this global issue necessitates the adoption of biologically based, cost-effective, sustainable, and environmentally friendly approaches. Among these, bacteriophages (phages) are highlighted as the most promising therapeutic agents for managing pathogens in aquaculture. Phages offer targeted pathogen control, mitigating antibiotic resistance and supporting the development of sustainable aquaculture practices.

3. Bacteriophages

Bacteriophages, often referred to as phages, are viruses that specifically target and infect bacteria, serving as therapeutic agents capable of lysing bacterial cells. The term "phage" is derived from "bacteria" and the Greek word phagein, meaning "to eat." Ubiquitously distributed in nature, phages are found in environments such as oceans, soil, food, and drinking water. With an estimated population of approximately 10^{31} individuals, they represent the most abundant biological entities on Earth (Le & Kurtböke, 2019; Yıldızlı et al., 2022).

Structurally, phages are composed of key components including a capsid, tail, and tail fibers. The capsid, made of protein subunits, houses the genetic material, while the tail facilitates the transfer of this material into the host bacterium. Although phages exhibit diverse structural features, the length and morphology of their tails vary among species (Linares et al., 2020).

Phages operate through two primary life cycles: the lytic and lysogenic cycles. In the lytic cycle, phages infect bacteria, replicate within them, and ultimately cause bacterial lysis, releasing new phage particles. This cycle involves several stages: adsorption, penetration, replication, maturation, and release. Due to their ability to eliminate pathogenic bacteria, lytic phages are preferred for therapeutic applications. Conversely, in the lysogenic cycle, the phage genome integrates into the bacterial chromosome and replicates passively with the host without causing immediate harm. However, environmental stressors can trigger the switch from a lysogenic to a lytic cycle (Joy, 2021).

Phage therapy involves utilizing the antimicrobial properties of phages to treat bacterial infections. With the rising prevalence of antibiotic resistance, phage therapy has garnered renewed interest since the 2000s. Notably, lytic phages have emerged as effective biological agents against pathogenic bacteria, offering a promising alternative to traditional antibiotics sustainable aquaculture practices.

3. Phage Therapy in Aquaculture

Phage therapy has gained increasing importance in combating bacterial infections in aquaculture. Common pathogens in aquaculture include *A. hydrophila*, *A. salmonicida*, *Vibrio anguillarum*, *Vibrio harveyi*, *Vibrio vulnificus*, *V. parahaemolyticus*, *Vibrio alginolyticus*, *E. tarda*, *Edwardsiella ictaluri*, *Edwardsiella piscicida*, *Flavobacterium columnare*, *Flavobacterium psychrophilum*, *Lactococcus garvieae*, and *Yersinia ruckeri* (Sieiro et al., 2020). The use of bacteriophages as alternatives to antibiotics offers sustainable solutions. Phage therapy is a promising approach in aquaculture, and its application has been increasingly adopted in recent years.

The primary step in phage therapy is the accurate identification of the pathogen causing the infection and the subsequent isolation of phages capable of effectively infecting the host bacteria.

Literature reviews spanning 1997 to 2022 indicate a growing trend in the use of bacteriophages in aquaculture (Fig 1.). Research has focused on the genetic and morphological characterization of phages, their use in biocontrol, and their therapeutic efficacy across different life stages of aquatic organisms (e.g., eggs, larvae, juveniles, and adults) (Donati et al., 2021). Frequently studied phage families include *Myoviridae*, *Podoviridae*, and *Siphoviridae*. These phages have demonstrated effectiveness against pathogens such as *A. salmonicida*, *A. hydrophila*, *E.tarda*, *Yersinia ruckeri*, *V. harveyi*, *V. parahaemolyticus*, *V. anguillarum*, *V. alginolyticus*, *Flavobacterium columnare*, *Flavobacterium psychrophilum*, *Lactococcus garvieae*, and *Streptococcus iniae* (Donati et al., 2021). Studies conducted in recent years on aquaculture are summarized in Table 1.

Phage delivery methods in aquaculture include direct suspension, oral application, and injection. Injection has been identified as the most effective preventive approach in the literature. Additionally, the development and commercialization of phage products have gained momentum. For instance, *Intralytix* has developed phages targeting *Vibrio spp.*, while *BAFADOR®* targets *Aeromonas spp.* and *Pseudomonas spp.* Furthermore, *ACD Pharma* has produced phage solutions for *Yersinia ruckeri*, including phage pellets for aquafeed, and *LUMI-NIL MBL* has been introduced to manage shrimp pathogens (Ansari & Nagar, 2024).

In several controlled investigations, aquatic organisms were experimentally challenged with specific bacterial pathogens and subsequently treated with varying doses of bacteriophages, resulting in statistically significant improvements across multiple indices of host resistance and pathogen suppression. For instance, Droubogiannis et al. (2023) demonstrated that gilthead seabream (*Sparus aurata*) larvae infected with *Vibrio harveyi* MM46 experienced a reduction in mortality from 49 % in untreated controls to 29 % following administration of the vB_VhaS_MAG7 phage, corresponding to an approximate 20 % increase in survival. Complementary in vitro assays further revealed that vB_VhaS_MAG7 produced a 33 % inhibition of bacterial proliferation within the first five hours post-infection. Similarly, Hossain et al. (2023) reported that specific-pathogen-free (SPF) shrimp exposed to 5×10^5 CFU mL^{-1} of *Vibrio parahaemolyticus* and treated with 1.5×10^6 PFU mL^{-1} of the vB_VpS_SHB15 phage—administered both prophylactically (–24, –6, –1 h) and therapeutically (+1 h)—showed marked reductions in mortality: from 100 % in positive controls to 93 % with therapeutic treatment alone, 53 % with prophylactic feeding, 33 % with prophylactic bath application, and only 6 % when both prophylactic and therapeutic regimens were combined. An accompanying in vitro planktonic growth assay indicated a 3-log reduction in bacterial load during the initial five-hour period following phage exposure. In a separate trial, Kumari et al. (2023) evaluated intramuscular and immersion delivery of a phage cocktail against *Aeromonas hydrophila* in *Pangasius buchanani*: fish inoculated with 8 × 10^5 CFU $fish^{-1}$ exhibited 100 % mortality in the absence of phage treatment, whereas groups receiving 1 × 10^4 and 1 × 10^5 PFU $fish^{-1}$ intramuscular injection achieved 93 % and 87 % survival, respectively. Delays of 6, 12, and 24 h in phage administration reduced survival to 83 %, 76.7 %, and 26.7 %, respectively. Conversely, simultaneous water immersion treatments at 1 × 10^5 and 1 × 10^6 PFU mL^{-1} conferred 93 % and 100 % protection, and even a 24-hour delayed immersion maintained 100 % survival. Collectively, these studies underscore the efficacy of phages characterized by high burst sizes and potent lytic activity, as well as the critical importance of optimized dosing schedules and delivery methods, in dramatically reducing both mortality and bacterial burdens in infected aquaculture species (Dang et al., 2021; Opperman et al., 2022).

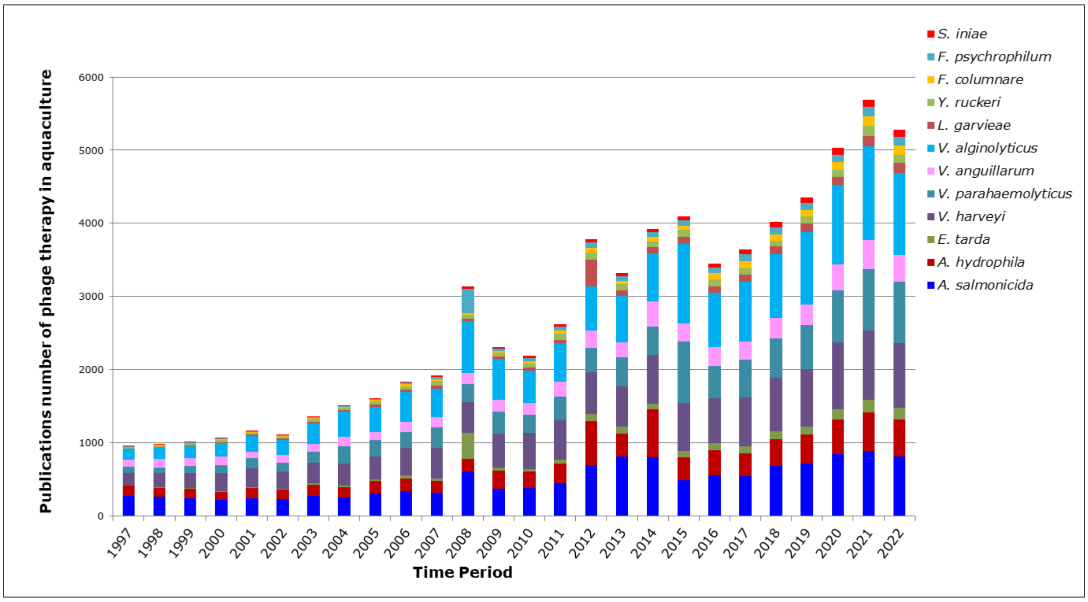


Figure 1. Literature reviews spanning 1997 to 2022 indicate a growing trend in the use of bacteriophages in aquaculture (Çağatay, 2023).

In controlled in vitro assays, *F. psychrophilum* biofilms at attachment, colonization and maturation stages were exposed to the lytic phage FPSV-D22 at varying phage-to-host ratios (PHRs), yielding >80 % inhibition of biofilm biomass with an initial PHR as low as 0.01; higher ratios further eradicated biofilm formation almost completely. Correspondingly, in an in vivo rainbow trout (*Oncorhynchus mykiss*) infection model, intraperitoneal administration of a phage cocktail (FPSV-D22 and FpV4) one day post-challenge with 8 × 10^7 CFU of *F. psychrophilum* reduced cumulative mortality from 67 % in untreated controls to 17 % and 13 % at PHRs of 2 and 0.02, respectively—equating to relative percentage survivals (RPS) of 76 % and 81 % (both $p < 0.001$ versus control)—whereas a PHR of 0.0002 conferred only 26 % RPS. These findings demonstrate that phages characterized by potent antibiofilm activity at low PHRs and robust in vivo efficacy can dramatically lower both biofilm biomass and fish mortality, underscoring their promise as biocontrol agents in aquaculture settings (Sundell et al., 2020). Additionally, phages targeting *F. psychrophilum* have been shown to enhance microbial diversity in aquatic ecosystems, providing protection before and after disease outbreaks (Imbeault et al., 2006).

Yersinia ruckeri and *T. maritimum* are additional pathogens that have been successfully targeted through phage therapy. Phages against *Y. ruckeri* reduced the prevalence of enteric redmouth disease by 75%, while those targeting *T. maritimum* improved the overall health of fish and prevented the spread of infections (Imbeault et al., 2006; Zhang et al., 2021).

On the other hand, some phage trials conducted in aquaculture have failed to achieve the desired outcomes due to inappropriate dosing, errors in the selection of administration methods, lack of phage standardization, the development of resistance, and unforeseen adverse factors. For example, a phage cocktail developed to control furunculosis in trout did not provide the expected protection. Despite continuous administration through feed, *Aeromonas salmonicida* infections could not be prevented, and disease symptoms and mortalities persisted within the fish population. Whether administered via feed, injection, or immersion, the phages failed to prevent fish deaths. This failure was attributed to the high contagiousness of *A. salmonicida* even at very low doses and the insufficiency of the applied phage doses to suppress the infection (Richards, 2014).

In another study targeting *Streptococcus iniae* infections, phage therapy initially appeared to reduce fish mortalities, but complete success was not achieved. Resistant bacterial strains were isolated from fish that had been treated with phages yet still died. This highlighted the potential for phages to carry resistance genes or mediate horizontal gene transfer, raising biosecurity concerns (Richards, 2014).

Similarly, studies using phage cocktails developed against *Vibrio parahaemolyticus* in shrimp revealed comparable issues. In controlled experiments, the overall mortality rate in phage-treated shrimp was only about 4% lower than that of the control group, a difference that was not statistically significant. Only a partial effect on the disease course was observed: in phage-treated shrimp, the onset of acute mortality was delayed by a few hours, but ultimate death was not prevented. Researchers reported that this outcome might have been due to the phages remaining viable on the shrimp surfaces for extended periods and unexpectedly affecting the shrimp's immune response negatively. These findings suggest that in rapid, toxin-mediated infections such as those caused by *Vibrio parahaemolyticus*, phage therapy alone may be insufficient (González-Gómez et al., 2023).

4. Effectiveness and Challenges of Phage Therapy in Aquaculture

Phage therapy is emerging as an effective method for combating bacterial infections in aquaculture. It not only targets bacteria but also serves as a natural solution that supports environmental sustainability. As an eco-friendly approach that maintains microbial balance in aquatic ecosystems, phage therapy holds great promise. However, its success depends on the interplay of various factors, including physical and chemical parameters of the water, species-specific characteristics of fish, environmental conditions, and the pathogenic potential of bacteria (Culot et al., 2019). Understanding these complex interactions is essential for the effective and safe application of phage therapy. Additionally, the administration methods and pharmacodynamic properties of the phages used are critical considerations. In aquatic ecosystems, fish immune systems and the genetic characteristics of pathogens play a pivotal role in determining the success of phage therapies (Ly-Chatain, 2014). Therefore, optimizing phage applications in aquaculture requires careful analysis of these intricate dynamics.

The success of phage therapy is closely tied to the specificity of phages to their target bacteria and the appropriate selection of phages. This specificity is vital not only for treatment efficacy but also for safety. Studies have demonstrated that phages are specific to their target pathogens, a conclusion often verified through host range tests (Fig. 2). Failure to accurately identify the target bacterial species may result in unsuccessful therapy. Once the bacteria are correctly identified, selecting the appropriate phage(s) is critical. Proper phage selection enhances treatment efficacy and minimizes potential side effects. Isolating phage strains with high titers is a fundamental step toward achieving successful therapeutic outcomes. However, the efficacy of phages is not solely determined by their specificity and titers but also by their virulence properties (Orndorff, 2016). Rigorous research can lead to the isolation of optimal phages for application. For instance, effective phage studies have been conducted against fish pathogens such as *Flavobacterium psychrophilum* and *Vibrio* spp. (Sundell et al., 2020).

Careful phage selection and rigorous standardization processes are essential before successful phage application can be achieved. Phages included in a cocktail should have a broad host range to effectively target common aquatic pathogens such as Vibrio, Aeromonas, and Flavobacterium (Huang and Nitin, 2019). The selected phages should show strong lytic activity, avoid lysogenic properties, and maintain stability under variable environmental conditions such as salinity, pH, and temperature fluctuations (Culot et al., 2019). In addition, when formulating the phage preparation to be used, it should be decided whether it will consist of a single phage or a combination of multiple phages. In both methods, phages infect the target bacteria by binding to their specific surface receptors and then destroy the host bacteria by lysis. The most important advantage of monophage therapy is that the treatment shows extremely high specificity against the target pathogen; thus, non-target microflora is not harmed and as a matter of fact, it has been reported that a single phage application does not disrupt the balance of the intestinal microbiota in infected fish.(Platt, 2000). However, the use of a single phage has some limitations in terms of therapeutic efficacy: Its spectrum of action is narrow and the risk of the target bacteria rapidly developing resistance through mechanisms such as mutation in the relevant phage receptor is high. Phage cocktails, on the other hand, offer a broader spectrum of action by reaching a wider range of hosts thanks to the different phages they contain and can increase the effectiveness of the treatment with the synergistic interaction of phages; in addition, the use of multiple phages reduces the selection pressure in the evolution of resistance by making it more difficult for bacteria to develop resistance to all phages at once. As a matter of fact, it has been shown in the literature that a two-phage cocktail controls the bacteria and reduces mortality more effectively compared to a single phage treatment in fish infected with *Aeromonas hydrophila* (Fazzino et al., 2020). Similarly, it has been reported that the survival rate in aquatic animals applied with a phage cocktail in a Vibrio-induced disease model was significantly higher (approximately 82%) compared to a single phage application; This rate is close to that achieved with conventional antibiotic therapy. In practice, the monophage strategy is often a “tailor-made” approach that requires identifying the responsible pathogen and selecting a specific phage for each new case, whereas phage cocktails offer a significant practical advantage in the field as “ready-made” formulations that can be prepared and rapidly applied against common pathogens (Ren et al., 2019). In addition, during cocktail design, it is important to ensure that phages target different bacterial receptors to prevent the development of cross-resistance; for example, combining phages that recognize outer membrane proteins and lipopolysaccharide structures increases the robustness of the cocktail (Mateus et al., 2014). Antagonistic interactions, where one phage interferes with the infection cycle of another, should be avoided, and phage-phage synergy should be confirmed by in vitro experiments such as spot tests and liquid culture inhibition tests (Chen et al., 2019). During the standardization phase, a multiplicity of infection (MOI) ranging from 0.01 to 1 is typically targeted to maximize bactericidal efficacy while avoiding phage overuse (Huang and Nitin, 2019). Furthermore, batch-to-batch consistency should be verified by measuring phage titers (expressed as PFU/mL), and long-term stability should be tested under appropriate storage conditions such as refrigeration or lyophilization with a shelf-life target of at least 6–12 months (Culot et al., 2019). The host range of the phage cocktail should be re-evaluated periodically, especially in open water systems where pathogen populations can rapidly evolve. Rigorous application of these selection and standardization principles is critical to the development of effective and commercially viable phage therapies to support sustainable aquaculture.

The first step of a successful phage therapy is a correct pharmacological approach. Pharmacokinetics is one of the two basic elements of pharmacology (the other is pharmacodynamics). Pharmacokinetics examines the characteristic properties and metabolic effects of the applied therapeutic agent. Therefore, the pharmacokinetic properties of phages play a key role in phage therapy (Abedon and Yin, 2009). When pharmacokinetic properties of phages are mentioned, the phage's burst size, latency period and adsorption period are understood (Castillo and Middelboe, 2016). In general, for phage therapy to be successful, it is desired that the phage first reaches the specific bacterium in a short time, lyses the bacteria in a short time after reaching it and releases a large number of virions into the environment. In this case, the phage with the shortest adsorption time, the shortest latent period and the largest burst size is always the phage that should be preferred first in phage therapy. Multiplicity of infection (MOI) guides treatment planning by defining the ratio of the applied phage dose to the bacterial load; in active treatment, kinetic properties such as burst size and latent period should be at an optimal level in order to achieve successful lysis even with low MOIs, while in passive approaches, direct bactericidal effect is achieved with high MOIs (Abedon, 2016). Host range shows the diversity of bacterial strains that the phage can infect; phages with a broad host spectrum can effectively lyse a large number of pathogen strains despite the genetic heterogeneity among clinical isolates, but specific binding property is also important in order not to harm non-target beneficial microflora. In terms of life cycle type, only obligate lytic phages are preferred; Phages with lysogenic potential can transfer toxin and resistance genes to the host bacteria due to the risk of integrating into the genome, therefore it is mandatory to meticulously analyze their entire genome for integrase, repressor and other genes associated with lysogeny (Howard-Varona et al., 2017). Genome stability ensures that the genetic structure of the therapeutic phage remains unchanged from production to application; since genetic deviations due to recombination, mutation and passage number may have negative effects on both effective lysis and safety profile, genome integrity should be monitored with long-term storage and serial passage tests (Pirnat et al., 2015). In addition, phages with “clean” genomes that do not have harmful genes (toxin and antibiotic resistance determinants) while carrying genes that may be beneficial should be used; in this direction, screening all phage candidates for virulence factors and resistance genes in databases such as VFDB and CARD by performing full genome sequencing and eliminating that phage in the presence of any risky genes is a basic security measure (Gholami et al., 2015). In this context, phages with high bursting efficiency, short latent period, rapid adsorption, effective multiplication at appropriate MOI, wide but specific host range, strict lytic cycle, robust genome stability, genome free of harmful genes and physical structure resistant to environmental conditions should be determined as the most suitable candidates before clinical application and should be tested in subsequent in vitro/in vivo models to verify the efficacy-safety balance.

Moreover, the formulation, dosage, and frequency of phage therapy are critical for effective pathogen control (Pereira et al., 2011). Developing suitable formulations tailored to fish species, age, and rearing environment will enhance therapeutic efficiency. However, formulating phages can sometimes be challenging. Among the advanced formulation techniques, microencapsulation has gained attention. Microencapsulation protects phage particles from environmental stressors and helps maintain their lytic activity over extended periods (Liang et al., 2023). In marine environments, where salinity and temperature fluctuations are common, microencapsulated phages demonstrate significantly improved stability (Dang et al., 2021). This technique also facilitates controlled release, optimizing the therapeutic process. Nanotechnology-based delivery systems represent another innovative approach that enhances the specificity and efficacy of phages. Phages combined with nanoparticles can reach target bacteria more rapidly, increasing treatment efficiency (Ye et al., 2019). For example, phages combined with nanoparticles for treating *A. hydrophila* infections have shown infection rates 30% lower than traditional methods (Imbeault et al., 2006).

Once suitable phages are characterized and formulated, scaling up their industrial production for aquaculture applications requires large-scale replication of beneficial phages. This process involves substantial costs associated with the cultivation of host bacterial strains, phage isolation, purification, and formulation development. Quality control testing must be conducted regularly to prevent contamination by unwanted bacteria or other organisms. Following production, appropriate cold chain logistics or storage conditions are necessary to deliver phages to fish farms. The rural or coastal location of most aquaculture facilities can increase transportation costs and logistical challenges. Therefore, achieving economic sustainability in the phage therapy process is essential for its widespread adoption. Regulatory procedures and customs regulations for international trade add further complexity to logistics planning, raising overall costs (Los, 2020).

Table 1. Significant Recent Bacteriophage Studies and Their Outcomes in Aquaculture.

Etiologic agent	Phage/Phages Cocktails	Fish/shellfish/ shrimp pecies	Outcomes	References
Aeromonas caviae	AC-P1, AC-P3	Tilapia, Catfish	Phages reduced mortality rates by 68% and showed significant lytic activity against antibiotic-resistant strains.	Nguyen et al., 2020
A.hydrophila	vB_AhaP_PT 2	Crucian carp	Survival rate reached 80% after phage treatment; reduced bacterial colonies in the intestine.	Liang et al., 2025
A. hydrophila	AVP3	Carp	Significant lytic activity against MDR strains; potential for biocontrol in aquaculture.	Kaur et al., 2024
A. hydrophila	AH-P10, AH-P12	Tilapia, Catfish	Phage application reduced mortality by 65% and demonstrated high efficiency against multidrug-resistant strains.	Wang et al., 2022
A. hydrophila	AHP1, AHP2	Common carp, Catfish	Phages showed strong lytic activity against multidrug-resistant *Aeromonas* strains and reduced mortality rates in infected fish populations.	Kazimierczak et al. 2018
A. salmonicida	Phage cocktail *A. salmonicida*	Salmonids	Phage therapy showed effective bacterial reduction in both in vitro and in vivo settings, providing an alternative to antibiotics for furunculosis control.	Vincent et al., 2019
Citrobacter spp.	Citrophage MRM19, Citrophage MRM57	Zebrafish (*Danio rerio*)	In vivo application in zebrafish increased survival rates by 17%-26%. The phages demonstrated high lytic activity, reducing bacterial load significantly.	Royam et al., 2020
E. tarda	ETP1, ETP5	Tilapia, Catfish	Phage cocktail effectively reduced *E. tarda* populations in aquaculture systems and improved survival rates in infected fish.	Ninawe et al. 2020
F. psychrophilum	FPSV-D22	Rainbow trout (*O. mykiss*)	Phages effectively disrupted biofilms and reduced mortalities in trout, even at low phage-to-host ratios.	Sundell et al. 2020
F. psychrophilum	FpV-1 to FpV-22,	*O. mykiss*	Phages with strong lytic potential against *F. psychrophilum* host	Stenholm et

	FpV2, FpV4, FpV7, FpV9, FpV10, FpV14, FpV18		strains thus provided the foundation for future exploration of the potential of phages in the treatment of both diseases.	al. 2008
P. damselae subsp. damselae	N4-like TEMp-D1	Marine species	Demonstrates high inhibition in PAS-treated groups; genomic characteristics support targeted therapy	Eren Eroğlu et al., 2025
Pseudomonas plecoglossicida	PP1, PP2	Ayu (*Plecoglossus altivelis*)	Phage therapy reduced bacterial loads significantly and minimized mortality rates in experimental infections.	Park and Nakai, 2003
Shewanella putrefaciens	SPX1	Shrimp	Reduced biofilm bacteria by over 98% on shrimp surfaces	Liu et al., 2025
Tenacibaculum maritimum	Prophages identified via in silico analysis	Atlantic salmon, European seabass	Key prophage elements identified for potential phage therapy; high stability and targeting efficiency	Ramírez et al., 2024
V. alginolyticus	vB_ValC_WD615	Tilapia, Catfish	Phage treatment reduced bacterial load significantly and showed stability across diverse temperature and pH conditions	Dai et al., 2024
V. alginolyticus	vB_ValC_RH2G	Grouper, Sea bream	Short latent period; efficient lysis with high specificity; genome indicates a new genus	Gao et al., 2023
V. alginolyticus	VA-2, VA-6	*Penaeus monodon* (Black tiger shrimp)	Phage application reduced mortality rates by 55% and improved water quality in aquaculture systems.	Huang et al., 2019
V. anguillarum	Lytic *Vibrio* phages	Marine fish species	Phage therapy effectively controlled *V. anguillarum* in marine aquaculture, reducing mortality rates and demonstrating its value in disease management.	Wong et al., 2024
V. anguillarum	Lytic *Vibrio* phages	*Dicentrarchus labrax*	Four lytic bacteriophages were isolated. The lytic phages inhibited the growth of their host bacteria, and TEM analysis revealed that phages belong to the *Myoviridae* and *Siphoviridae* family. One-step growth experiments showed that these lytic phages have different latent	Yıldızlı et al., 2022

			periods (30–50 minutes) and high burst sizes. Finally, Phage therapy effectively controlled *V. anguillarum.*	
Vibrio diabolicus	vB_Vc_SrVc 2	White shrimp	Delayed mortality onset by 40 hours and reduced mortality significantly	Lomelí-Ortega et al., 2024
V. harveyi	VH5, VH10, VH20	Shrimp, Grouper fish	Phage therapy reduced bacterial loads in infected shrimp and prevented disease outbreaks in aquaculture farms.	Misol et al.
Vibrio nereis	vB_VneM_N B-1	Sea cucumber (*Apostichopus japonicus*)	Reduced coelomocyte apoptosis and infection severity	Cao et al., 2025
V. parahaemolyticus	vB_Vp_PvV p04	Shrimp (*Penaeus vannamei*)	Encapsulation + freeze-drying method showed stable efficacy; 87.6% bacterial inhibition observed	Peña-Rodríguez et al., 2025
V. parahaemolyticus	vB-VpaS-SD15 (P15)	Shrimp (*Penaeus vannamei*)	Efficient lysis of 33 *V. parahaemolyticus* strains; stable across broad temperature and pH ranges	Chen et al., 2024
V. parahaemolyticus	*Vibrio*-specific phages	Shrimp	Field trials showed improved survival and health; low bacterial resistance emergence	Hossain et al., 2024
V. parahaemolyticus	vB_VpaS_P G07	Shrimp (*Penaeus vannamei*)	The phage significantly reduced shrimp mortality rates when applied after bacterial exposure, highlighting its effectiveness in AHPND management.	Ding et al., 2020
Vibrio spp.	IKEM_vK, IKEM_v5, IKEM_v14	General aquaculture species	Broad host range; stability across pH 6–11; significant biofilm inhibition	Yaşa et al., 2024

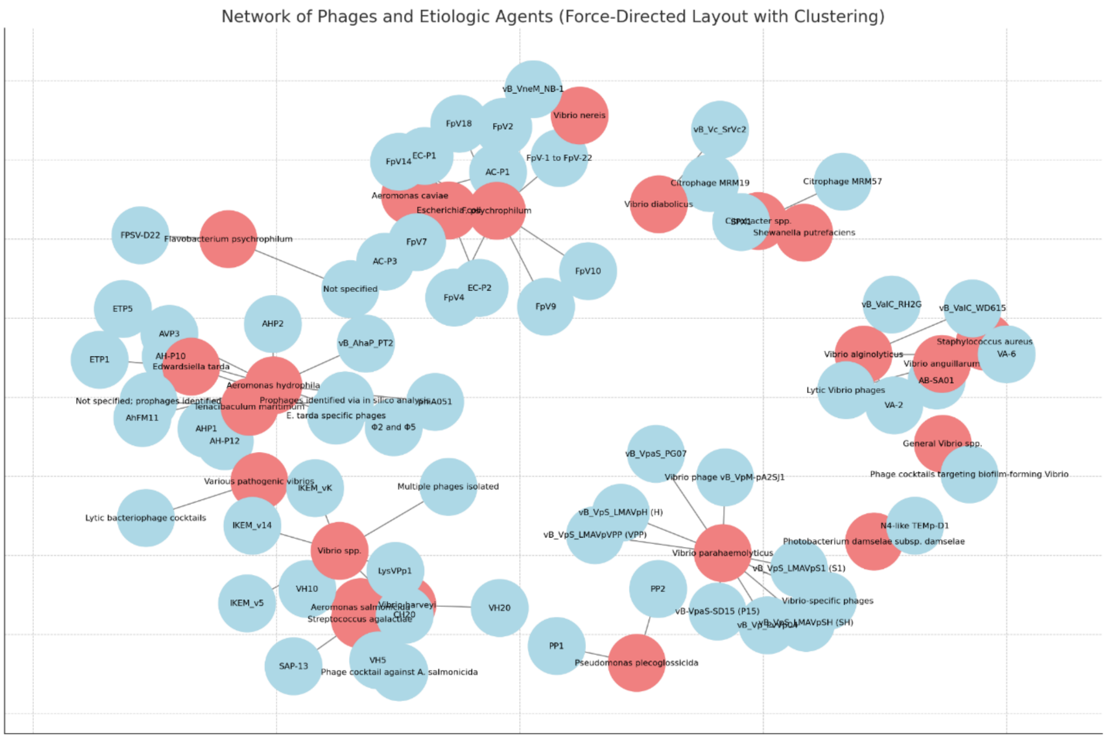


Figure 2. Key Phages Used in Phage Therapy in Aquaculture in Recent Years and Their Complex Relationships with Target Pathogens (The figure was created using Python 3.10 along with the open-source libraries networkx and matplotlib. The layout was generated using the force-directed (spring layout) algorithm.).

The method of application is another critical factor affecting the success of phage therapy. The choice of bacteriophage application route in fish farming depends on factors such as the nature of the infection, farm size, phage preparation cost, and fish species; the three commonly used methods of application in aquaculture are immersion (bath), injection, and oral administration. (Kunttu et al., 2021). Application by injection (usually intraperitoneal) allows phages to be delivered directly to the fish body and shows the highest therapeutic efficacy in systemic infections; since phages quickly enter the circulation and spread to the target organs in parenteral administration. The disadvantages of this method are the difficulty of applying it in large flocks due to the time-consuming and invasive process and the risk of stress-related mortality in fish. In fact, in one study, administration of phages by injection in trout with systemic infection caused by Flavobacterium increased survival from 56.7% to 80% compared to the control group. Oral administration (administration of phages with feed) is one of the most frequently preferred methods in aquaculture because it is practical, low-cost, and allows simultaneous treatment of large numbers of fish with minimal stress. However, phages administered orally may be adversely affected by the harsh conditions in the digestive system of the fish; stomach acidity and the presence of proteolytic enzymes can significantly reduce the infectivity of phages. To overcome this problem, methods such as adding acid neutralizers to the phage suspension or loading phages onto feed particles with acid-resistant protective coatings are used. In addition, the survival of coated phages on dry feed during storage is considered critical in terms of long-term efficacy and commercial viability. In addition, phages administered orally may have limited ability to cross the intestinal mucosa and enter the systemic circulation (Christiansen et al., 2014). Nevertheless, some studies have shown that orally administered phages can pass through the intestinal wall and be detected in internal organs when appropriate formulations are used; even successful treatment of *Pseudomonas plecoglossicida* infections in ayu fish and *F. columnare* infections in catfish has been reported with phage-coated feed. Another study showed that phages administered orally against *Vibrio alginolyticus* reduced infection rates by more than 50%, while prophylactic phages increased immune responses in fish (Liang et al., 2023). In the immersion (bath) method, fish are treated by immersing them in phage-containing water. This approach allows rapid processing of a large number of fish and contributes to the control of infections in these areas since it directly affects the external mucosal surfaces of the fish, such as the skin and gills. For example, in a disease model caused by *F. columnare*, phage bath application prevented the development of infection and provided 100% survival in zebrafish (control 0%) and ~50% survival in trout (control 8.3%). However, the effectiveness of the immersion method under field conditions may be limited due to the difficulty of maintaining sufficient phage concentration in water and the rapid dilution and inactivation of phages. For effective treatment, it is generally necessary to use high concentrations of phages and, if necessary, to perform repeated applications; Indeed, some experimental studies have reported that phages administered only by immersion did not provide a statistically significant benefit in controlling the target infection, whereas significant improvement was achieved when administered by injection (Laanto et al., 2015).

In conclusion, phage therapy offers immense potential for combating bacterial pathogens and maintaining microbial balance in aquatic ecosystems. Addressing challenges such as phage characterization, industrial production, environmental impacts, resistance mechanisms, application methods, and regulatory frameworks will be critical to realizing its full potential. Expanding research and promoting sustainable applications can support both effective infection management and environmentally sustainable aquaculture practices.

5. Risks and Limitations of Phage Applications in Aquaculture

Phage therapy is seen as a promising alternative in combating bacterial diseases in the aquaculture sector. However, there are several barriers preventing the sustainable and widespread application of phages in aquaculture. Significant risks and limitations include the potential for bacteria to develop resistance to phages, problems related to horizontal gene transfer, and gaps in regulatory frameworks. This section addresses the risks and limitations associated with phage therapy applications in aquaculture.

Phages—particularly temperate (lysogenic) phages—can mediate horizontal gene transfer between host bacteria, potentially carrying antibiotic resistance genes or virulence factors (Geetha et al., 2020). Lysogenic phages can integrate their genome into the bacterial chromosome, enabling the transmission of genes to surrounding bacteria via a process called transduction. This presents a serious risk (Colavecchio et al., 2017). Instead of harming target pathogenic bacteria, lysogenic phages may spread undesirable genes like antibiotic resistance or virulence factors to other environmental bacteria. Therefore, the ability of lysogenic phages to mediate horizontal gene transfer represents a significant safety concern in phage therapy. The use of lysogenic phages carrying resistance or virulence genes could undermine the efficacy of phage applications and lead to major biosecurity risks. Consequently, it is recommended that only lytic (virulent) phages be used in therapy, as they reproduce by lysing the host cell and have minimal potential for gene transfer (Schulz et al., 2022). Although some studies suggest that resistance genes carried by phages may be non-functional and that data on in vivo transduction are limited, excluding high-risk phages from therapy remains an important safety precaution.

Bacterial resistance mechanisms pose a significant challenge to phage therapy, similar to antibiotics. Despite optimal phage formulations and methods, bacteria can develop resistance, threatening the efficacy of phage therapy. Bacteria can counter phages using mechanisms like the CRISPR-Cas system, which enables them to recognize and neutralize phages based on previously encountered genetic material. To mitigate resistance, strategies such as phage cocktails combining multiple phages have shown promise. This approach complicates resistance development and enhances treatment efficacy (Forti et al., 2018). Combining phages with antibiotics can also create synergistic effects, improve treatment outcomes and reduce bacterial resistance rates. The combined use of phages and antibiotics in aquaculture is an innovative and promising strategy. Depending on the application conditions, these combinations can show synergistic effects such as filamentation, depolymerase, temperature phase synergy (tPAS), modulation of surface receptors, evolutionary trade-offs, desensitization of persister cells, use of phase-induced lysozymes (endolysin/lysin), and efflux pump disruption (Jo et al., 2016). Among these synergy mechanisms, filamentation and depolymerase have been reported as the most frequently encountered synergy mechanisms. Some antibiotics can trigger filamentous cell extension (filamentation) in bacteria, increasing the effectiveness of phage infection, and enzymes such as depolymerase secreted by phages can facilitate the penetration of antibiotics into these protected structures by breaking down the biofilm matrix. These interactions play an effective role in controlling pathogenic bacteria and provide significant benefits by increasing treatment efficacy and especially in controlling persistent infections caused by biofilms (Möller et al., 2013). On the other hand, there are also cases where antagonistic interactions are observed: for example, some bacteriostatic antibiotics inhibit bacterial protein synthesis and prevent phage proliferation, and when applied together, the total antimicrobial effect may be lower than expected (Torres-Barceló et al., 2018). Therefore, in order for these combinations to be successful in aquaculture applications, the selection of appropriate phage and antibiotic species and the dose and sequence to be applied must be carefully determined. When planned appropriately, this approach can reduce antibiotic use in aquaculture and stand out as a valuable tool in combating resistant pathogens and biofilms.

Furthermore, the uncontrolled release of phages into aquatic ecosystems may impact not only the target pathogen but also indirectly affect natural microbial communities (Álvarez & Biosca, 2025). Phages play a key role in shaping bacterial population dynamics in natural environments; in marine water, they are reported to eliminate up to 40% of bacterial biomass daily. Introducing high concentrations of foreign phages into aquaculture systems may cause unexpected ecological shifts. For example, studies in agricultural environments suggest that intense phage addition could lead to widespread resistance selection and the emergence of bacterial populations unresponsive to future phage therapies (Oliveira et al., 2012). Additionally, the normally balanced microbial community structure could be disrupted. Although phages are more targeted than antibiotics, introducing external phages into an ecosystem can disturb the existing bacterial equilibrium. In one study, applying phages to the microbial community inside marine sponges led to the disappearance of certain low-abundance bacterial species while opportunistic bacteria like *Vibrio* proliferated dramatically, significantly altering community structure (Hossain et al., 2024). Such microbial imbalances can impact overall ecosystem health and increase the risk of new, unexpected infections. Moreover, once phages are released into the environment, they cannot be selectively retrieved; as long as suitable hosts are available, they continue to propagate. Therefore, it is critical to assess the environmental impacts of phage applications through small-scale preliminary trials and carefully monitor unintended ecological consequences.

Phages generally exhibit high host specificity. While this specificity protects beneficial microbiota by sparing non-target bacteria—a significant advantage—it also poses practical limitations. A phage may not effectively control multiple pathogens or variant strains present in a complex aquatic environment. Thus, the use of phage cocktails is often necessary (Liu et al., 2022). Combining different phages expands the host range and enables simultaneous targeting of multiple bacterial threats in aquaculture. For example, a phage narrowly targeting *Vibrio* species alone may be ineffective against other pathogens, whereas a cocktail can offer broader protection (Aziz et al., 2024). Using well-characterized phages minimizes off-target effects; however, if a phage's host range is poorly understood or if a benign environmental bacterium shares similar antigenic structures with a target pathogen, unintended targeting could occur. Therefore, careful determination of phage host ranges and strict selection criteria are essential for safe and effective therapy. In short, phage specificity is a double-edged sword: it minimizes collateral damage when used correctly but limits the breadth of application, requiring a tailored phage for each pathogen.

Environmental stability—the durability and activity duration of phages in aquaculture settings—is another key factor influencing therapeutic success. Parameters such as water pH, salinity, temperature fluctuations, and organic load can affect phage survival and infectivity. For instance, phages administered orally via feed face harsh conditions in the fish gastrointestinal tract, such as acidic pH and digestive enzymes that may inactivate phage particles. Studies show that phage suspensions rapidly lose viability due to stomach acid and proteases, indicating a need for protective formulations like encapsulation or enteric coating for oral delivery (Islam et al., 2017). Additionally, ensuring the survival of phages on dry feed pellets during high-temperature pelleting and long-term storage presents challenges. While some phages show broad stability across pH (6–11) and temperature (4–50°C) ranges, others are more fragile (Rai et al., 2023). Ultraviolet (UV) light from sunlight is another destabilizing factor for phages in open systems, as it can damage phage DNA and inactivate them, leading to preferred application in shaded or evening conditions. Dilution of phages in large water bodies may also reduce their effectiveness; achieving the necessary infective dose in vast ponds or sea cages is practically challenging. Effective biocontrol often requires a high phage-to-bacteria ratio, which is difficult to maintain under real-world aquaculture conditions (Oliveira et al., 2012). Therefore, phages in the application field often necessitate repeated dosing or specialized formulations such as microencapsulation or protective additives.

In recent years, regulatory frameworks for the therapeutic use of phages have remained unclear compared to those for conventional veterinary drugs. In many countries, phages have not been fully categorized as either vaccines or drugs, complicating approval and licensing procedures. Current regulations often require the registration of a single phage species as a product, whereas in practice, effective treatment usually requires phage cocktails. Registering a cocktail demands individual approval and evaluation of each phage, making the process bureaucratically burdensome and time-consuming (Sieiro et al., 2020). Globally, only a few commercial phage products have been approved, and none have been developed specifically for aquaculture. Although agencies such as the European Medicines Agency (EMA) emphasize the need for faster adoption of phage therapy in veterinary fields, existing frameworks are poorly adapted to the unique biological nature of phages, treating each application almost as an exceptional case. Regulatory agencies remain cautious, requiring extensive data on environmental impacts and horizontal gene transfer risks, particularly for phage cocktails (Culot et al., 2019). For instance, proving the safety of multi-phage preparations for fish and the environment involves more complex assessments than single-compound drugs. Additionally, regulatory ambiguity exists regarding whether phages are classified as prophylactic or therapeutic agents, which influences the applicable regulations. In the United States, some phage preparations have been approved under the "Generally Recognized As Safe" (GRAS) status for food safety applications (e.g., anti-*Listeria* preparations in food processing), but a similar pathway has yet to be established for veterinary use in aquaculture (Aquaculture and Aquaculture Drugs Basics, 2020). Overall, regulatory uncertainty remains one of the biggest barriers to the commercialization of phage therapies. Clear guidelines and the development of specific frameworks for phages (e.g., under EU Regulation 2019/6) are critical for wider adoption in the industry. Phage therapy products have been classified as 'novel therapies' under Regulation (EU) 2019/6 as of 1 January

2022, and the special provisions added to Annex II by Regulation (EU) 2021/805 envisage a flexible, risk-based approach to the quality, safety and efficacy requirements for phage therapy VMPs. In this context, EMA's 13 October 2023 guideline mandates that marketing-authorization dossiers for monophage or polyphage cocktails systematically address critical quality attributes (CQAs), monitor process parameters (CPPs), provide genomic and phenotypic characterization, confirm the lytic lifecycle and demonstrate absence of toxin/resistance genes in their quality documentation. The guideline further details the structure of Post-Approval Change Management Protocols (PACMPs), the procedures for adaptive variation applications, and the comparability assessment of monophage components in accordance with ICH Q5E principles, thereby enabling compositional updates in response to geographic or resistance-profile variations while ensuring that each change remains controllable in terms of quality, safety and efficacy. This approach simultaneously upholds transparency, predictability and openness to innovation throughout both pre- and post-authorization phases of phage therapy VMPs, enhancing regulatory flexibility and patient access (European Medicines Agency, 2022).

Finally, scaling up laboratory-scale successful phage applications to industrial-scale use presents practical challenges. Commercial production requires standardized processes to produce sufficient quantities of high-quality phages. Since phages are propagated using host bacteria, residual bacterial contaminants must be carefully removed to avoid the presence of endotoxins or exotoxins in the final product (Hietala et al., 2019). Although clinical-grade phage preparations undergo sterility and endotoxin testing, concerns persist regarding possible unwanted elements like pathogenicity islands or toxic proteins (Rai et al., 2023). Therefore, achieving contamination-free phage products according to Good Manufacturing Practices (GMP) remains a significant hurdle. Consistency between production batches is also critical; phage concentration and efficacy must not vary (Jassim & Limoges, 2014). Additionally, storage and shelf-life stability must be ensured: liquid phages require cold chain logistics, while lyophilized forms must retain stability during storage (Muramatsu et al., 2022). These technical aspects are not yet as mature or cost-effective as antibiotic production.

In conclusion, although phages hold significant potential for pathogen control in aquaculture, unresolved issues such as horizontal gene transfer risks, uncontrolled ecological impacts, resistance development, and gaps in regulatory frameworks remain major barriers and limitations to their widespread adoption. Once these challenges are carefully addressed and solutions are developed, the use of phages in aquaculture is expected to become much more widespread.

6. Phage Application Strategies, Biotechnological Advances and Genetic Modifications

In recent years, genetic engineering techniques have been employed to enhance the therapeutic efficacy of phages. Genetically modified phages have been found to exhibit higher specificity against pathogens and greater resilience to environmental conditions. Additionally, phages equipped with CRISPR-Cas9 technologies not only target pathogens but also support natural microbial communities (Ye et al., 2019). These innovations aim to establish lasting therapeutic success for phages while offering a complementary approach to existing methods.

Phage therapy, as a rapidly advancing field of next-generation biological agents for pathogen control, is being significantly expanded by genetic modification techniques. Genetic engineering plays a vital role in increasing phage specificity, preventing resistance development, and creating more environmentally resilient phages. Moreover, innovative technologies such as synthetic biology and CRISPR-Cas have introduced groundbreaking applications that enhance the therapeutic efficacy and flexibility of phages. By optimizing the characteristics of phages, genetic engineering seeks to increase their therapeutic potential. Modified phages are particularly effective against pathogens that have developed antibiotic resistance (Sundell et al., 2020). For example, genetically engineered phages can target antibiotic resistance genes, deactivate them, and directly inhibit the development of resistance. Another key application is the optimization of the life cycle. Enhanced lytic phages can replicate more rapidly and effectively in infected areas, significantly reducing pathogen loads. Studies have demonstrated that genetically modified phages effectively reduce infection rates caused by common aquaculture pathogens such as *Flavobacterium psychrophilum* and *Vibrio* spp. (Imbeault et al., 2006;).

CRISPR-Cas systems represent an innovative technology enabling the genetic engineering of phages for increased specificity. CRISPR-equipped phages selectively target pathogenic bacteria while maintaining the balance of microbial communities in aquatic ecosystems. For instance, studies utilizing CRISPR-phage combinations against antibiotic-resistant bacteria like *Aeromonas hydrophila* have reported effective pathogen elimination (Sundberg et al., 2021). In another study, targeted genome editing was performed on the phage TT4P2 derived from *Vibrio natriegens* using CRISPR–Cas9 technology. The *orf6* gene of the phage was excised and replaced with a gene encoding lysozyme, thereby enhancing bacterial cell lysis. This high-efficiency modification, achieved through a dual-plasmid system, enables the development of genetically engineered, effective, and customized phages for use in aquaculture. (Zhang et a., 2022). In another study, a combination of the natural lytic phage CH20 and its recombinant endolysin (LysVPp1) was evaluated as a preventive strategy against *Vibrio*-induced infections during the larval stage in aquaculture. The lytic phage CH20 was isolated from *Vibrio alginolyticus*, and the gene encoding the endolysin was cloned via synthetic biology into an *E. coli* expression system, where it was purified as a His-tagged recombinant protein. The lytic activity of this protein was tested against logarithmic-phase cultures of *V. alginolyticus*, *V. parahaemolyticus*, and *V. splendidus*, and its efficacy was confirmed through optical density reduction. In combination therapy trials administered to live feed (rotifers) and gilthead sea bream (*Sparus aurata*) larvae, both *Vibrio* load and larval mortality rates were monitored. The results demonstrated that the phage–endolysin combination significantly reduced bacterial load and improved larval survival compared to treatments with the phage or endolysin alone. These findings highlight the potential of engineering-based phage therapies as effective biocontrol strategies for early life stages of fish in aquaculture (Romeo et al., 2024). Choudhury et al. (2019) developed a recombinant lysozyme (r-lysozyme)-supported approach to enhance the therapeutic efficacy of phage applications targeting *Vibrio harveyi* infections. In their study, a lytic phage specific to *V. harveyi* was first isolated and characterized. Subsequently, a recombinant shrimp lysozyme gene was cloned into an expression vector and produced in an *E. coli* system. The purified lysozyme protein was co-applied with the phage to *V. harveyi* cultures under various environmental conditions (pH 5–9, salinity 5–35 ppt) in vitro, and bacterial lysis was monitored by changes in optical density (OD600). In parallel, microcosm models simulating brackish water environments similar to shrimp aquaculture systems were established to assess the effects of the phage, lysozyme, and their combination on bacterial load. The results revealed that the addition of r-lysozyme significantly enhanced the lytic effect by promoting phage adsorption and cell wall degradation. This bioengineering-based strategy is particularly promising against *Vibrio* infections in shrimp farming (Choundry et al., 2019). Furthermore, CRISPR-Cas systems enhance the genetic durability of phages, making them more stable against environmental factors (Ye et al., 2019). As a result, controlling resistant bacteria in aquatic environments becomes more efficient and sustainable.

Recent advancements in biotechnological methods and artificial intelligence applications have facilitated the design of synthetic phages. These phages can be genetically modified to target specific pathogens and are produced more controllably than natural phages. For instance, synthetic phages designed against *Vibrio parahaemolyticus* have shown a broader spectrum of activity and greater stability under environmental conditions compared to natural phages (Dang et al., 2021; Liang et al., 2023). This technology is expected to revolutionize the aquaculture industry. Additionally, genetic engineering enables phages to acquire new functions, such as antibiotic production, toxin neutralization, or enhancing immune responses. For example, phages carrying genes to boost fish immune responses have been shown to reduce disease incidence and improve growth rates (Kunttu et al., 2021). These multifunctional phages provide an innovative solution that combines treatment and protection applications in aquaculture.

On the other hand, preventing resistance development is critical for the long-term success of phage therapy. Genetic engineering allows phages to be modified for continuous evolution against bacteria. Moreover, phage cocktails targeting multiple pathogens simultaneously have proven to be an effective strategy in reducing resistance development (Sundell et al., 2020). This approach significantly slows resistance acquisition as pathogens encounter multiple defense mechanisms concurrently.

The successful implementation of phage therapies depends on integrating innovative technologies and developing appropriate application strategies. Techniques such as microencapsulation, nanotechnology, and genetic engineering enhance the efficacy of phages, paving the way for broader adoption in the aquaculture sector. These advancements not only support environmental sustainability by reducing antibiotic usage but also help mitigate economic losses in aquaculture.

7. Conclusion

Aquaculture has become an increasingly vital sector in meeting the global demand for animal protein. However, the intensification of farming practices has been accompanied by a rise in infectious diseases, prompting the widespread use of antibiotics. This in turn has led to the emergence of antibiotic-resistant bacterial strains, posing a critical challenge for both aquatic animal health and environmental sustainability. In light of this, bacteriophage therapy has attracted increasing interest as an alternative.

Phage therapy offers the unique advantage of targeting specific bacterial pathogens without disturbing the beneficial microbiota of the aquatic environment. Nonetheless, several limitations impede its widespread application, such as phage-host specificity and the genetic diversity of pathogenic bacteria. These challenges necessitate integrated strategies combining traditional approaches with emerging biotechnological tools.

Recent advances in molecular biology and genetic engineering have opened new avenues to enhance the efficacy of phage therapy. Notably, CRISPR-Cas systems have been employed to edit phage genomes, allowing the construction of recombinant phages with broader host ranges, improved LYTIC activity, or engineered payloads such as antimicrobial peptides and lysins. For instance, CRISPR-mediated deletion or insertion of genes into phage genomes has enabled the design of phages with enhanced antibacterial capabilities against aquaculture-relevant pathogens such as *Vibrio spp.* and *Aeromonas spp.* Furthermore, the co-application of recombinant lysins and phages has demonstrated synergistic effects in reducing pathogen loads in larval rearing systems, improving survival rates without resorting to antibiotics.

In conclusion, the integration of phage therapy with genetic engineering technologies such as CRISPR represents a transformative approach for disease control in aquaculture. While traditional phage therapy alone faces limitations in field conditions, the development of engineered phages tailored for enhanced stability, spectrum, and efficacy offers a promising path forward. These innovations not only respond to the urgent need to reduce antibiotic dependency but also align with the goals of sustainable aquaculture production. Moving forward, interdisciplinary research that bridges microbiology, aquaculture, and biotechnology will be essential to develop robust, scalable, and regulatory-compliant phage-based solutions for the industry.

8. Compliance with Ethical Standard

a) Author Contributions
Single author.

b) Conflict of Interests
The authors declared that they have no conflict of interest.

c) Statement on the Welfare of Animals
Not relevant

d) Statement of Human Rights
There are no human subjects in this study.

e) Funding
This study was not supported by any founder.

9. References

Abedon, S. T., & Yin, J. (2009). Bacteriophage plaques: theory and analysis. In *Bacteriophages: Methods and Protocols, Volume 1: Isolation, Characterization, and Interactions* (pp. 161-174). Totowa, NJ: Humana Press.

Abedon, S. T. (2016). *Phage therapy dosing: The problem(s) with multiplicity of infection (MOI).* https://doi.org/10.1080/21597081.2016.1220348

Álvarez, B., & Biosca, E. G. (2025). Harnessing the Activity of Lytic Bacteriophages to Foster the Sustainable Development Goals and the "One Health" Strategy. https://doi.org/10.20944/preprints202501.2210.v1

Ansari, F., & Nagar, V. (2024). Aeromonas Biocontrol Using Bacteriophages: A Promising Strategy.

Aquaculture and Aquaculture Drugs Basics. (2020). https://www.fda.gov/animal-veterinary/animal-health-literacy/aquaculture-and-aquaculture-drugs-basics

Aziz, N. S., Ibrahim, S., Zaharinie, T., & Tang, S.-S. (2024). Bacteriophage encapsulation – Trends and potential applications in aquaculture. Aquaculture, 594, 741398. https://doi.org/10.1016/j.aquaculture.2024.741398

Batchelder, J. I., Hare, P. J., & Mok, W. W. K. (2023). Resistance-resistant antibacterial treatment strategies. Frontiers in Antibiotics, 2. https://doi.org/10.3389/frabi.2023.1093156

Baytaroglu, E. S., & Kucukkagnici, O. (2025). Screening of Aeromonas spp. and their antimicrobial resistance profiles in wild fish and seawater from the Gulf of Antalya, Mediterranean Sea. *Eurasian Journal of Veterinary Sciences*, *41*.

Çağatay, T., İ. (2023). Bacteriophage applications in aquaculture. Israeli Journal of Aquaculture-Bamidgeh, 75(2).

Cao, Z., Liu, X., & Zhang, Y. (2020). Environmental factors influencing bacteriophage stability and efficacy in aquaculture. Environmental Science & Technology 22(3):187–194.

Castillo, D., & Middelboe, M. (2016). Genomic diversity of bacteriophages infecting the fish pathogen Flavobacterium psychrophilum. *Microbiology Letters*, *363*(24), fnw272.

Chen, D., Wang, Z., Li, X., Du, H., Zhang, K., Cao, S., et al. (2024). Biological properties of Vibrio parahaemolyticus lytic phages and transcriptome analysis of their interactions with the host. Aquaculture Reports 39:102450.

Choudhury, T. G., Nandi, S. P., & Saikia, B. (2019). Influence of some environmental variables and addition of r-lysozyme on efficacy of Vibrio harveyi phage for therapy. *Journal of Biosciences*, *44*(1), 8. https://doi.org/10.1007/s12038-018-9830-x

Christiansen, R. H., Dalsgaard, I., Middelboe, M., Lauritsen, A. H., & Madsen, L. (2014). Detection and quantification of Flavobacterium psychrophilum-specific bacteriophages in vivo in rainbow trout upon oral administration: implications for disease control in aquaculture. *Applied and Environmental Microbiology*, *80*(24), 7683-7693.

Colavecchio, A., Cadieux, B., Lo, A., & Goodridge, L. (2017). Bacteriophages Contribute to the Spread of Antibiotic Resistance Genes among Foodborne Pathogens of the Enterobacteriaceae Family – A Review Frontiers in Microbiology, 8. Frontiers Media. https://doi.org/10.3389/fmicb.2017.01108

Culot, A., Grosset, N., & Gautier, M. L. (2019). Overcoming the challenges of phage therapy for industrial aquaculture: A review [Review of Overcoming the challenges of phage therapy for industrial aquaculture: A review]. Aquaculture, 513, 734423. https://doi.org/10.1016/j.aquaculture.2019.734423

Dai, L., Wu, J., Chen, R., Zhang, R., Zhang, Y., & Wei, W. (2024). Isolation and characterization of a novel bacteriophage against Vibrio alginolyticus from coastal waters and its environmental tolerance. Virology 600:110219.

Dang, W., Wu, J., & Chen, L. (2021). Bacteriophage cocktails: Development and applications in aquaculture. Journal of Marine Biotechnology 28(7):789–804.

Ding, T., Sun, H., Pan, Q., Zhao, F., Zhang, Z., & Ren, H. (2020). Isolation and characterization of Vibrio parahaemolyticus bacteriophage vB_VpaS_PG07. Virus Research 286:198080. https://doi.org/10.1016/j.virusres.2020.198080. PMID: 32615132.

Donati, V., Dalsgaard, I., Sundell, K., Castillo, D., Er-Rafik, M., Clark, J., Wiklund, T., Middelboe, M., & Madsen, L. (2021). Phage-mediated control of Flavobacterium psychrophilum in aquaculture: In vivo experiments to compare delivery methods. Frontiers in Microbiology. https://doi.org/10.3389/fmicb.2021.628309.

Droubogiannis, S., Pavlidi, L., Skliros, D., Flemetakis, E., & Katharios, P. (2023). Comprehensive characterization of a novel bacteriophage, vB_VhaS_MAG7 against a fish pathogenic strain of Vibrio harveyi and its in vivo efficacy in phage therapy trials. International Journal of Molecular Sciences 24(9):8200. https://doi.org/10.3390/ijms24098200.

Eroğlu, A. E. E., & Yaşa, İ. (2025). Genomic overview of the N4-like TEMp-D1 phage and the efficacy of antibiotic-phage synergy for the biocontrol of Photobacterium damselae subsp. damselae. Aquaculture International 33(1):1–19. https://doi.org/10.1007/s10499-024-01234-9.

European Medicines Agency. (2022). Guideline on Quality, Safety and Efficacy of Veterinary Medicinal Products Specifically Designed for Phage Therapy, 13 October 2023, EMA/CVMP/NTWP/32862/2022.

Fabrega, J., & Carapeto, R. (2020). Regulatory review of the environmental risk assessment of veterinary medicinal products in the European Union, with particular focus on the centralised authorisation procedure. Environmental Sciences Europe, 32(1). https://doi.org/10.1186/s12302-020-00374-x

Fazzino, L., Anisman, J., Chacón, J. M., & Harcombe, W. R. (2020). Phage cocktail strategies for the suppression of a pathogen in a cross-feeding coculture. *Microbial Biotechnology*. https://doi.org/10.1111/1751-7915.13650

Feng, Y., Cao, S., Qin, Z., Ouyang, P., Chen, D., Guo, H., Fang, J., Deng, H., Li, W., & Geng, Y. (2022). Comparative analysis of sturgeon- and catfish-derived Yersinia ruckeri reveals the genetic variation and the risk of heavy antibiotic resistance. Aquaculture Reports. https://doi.org/10.1016/j.aqrep.2022.101231.

Forti, F., Roach, D. R., Cafora, M., Pasini, M. E., Horner, D. S., Fiscarelli, E., Rossitto, M., Cariani, L., Briani, F., Debarbieux, L., & Ghisotti, D. (2018). Design of a broad-range bacteriophage cocktail that reduces Pseudomonas aeruginosa biofilms and treats acute infections in two animal models. Antimicrobial Agents and Chemotherapy. https://doi.org/10.1128/AAC.02573-17.

Gao, Z., Piao, Y., Hu, B., Yang, C., Zhang, X., Zheng, Q., & Cao, J. (2023). Investigation of antibiotic resistance genotypic and phenotypic characteristics of marine aquaculture fish carried in the Dalian area of China. Frontiers in Microbiology. https://doi.org/10.3389/fmicb.2023.1222847.

Geetha, P., Swaminathan, T. R., Kumar, V. J. R., & Singh, I. S. B. (2020). Antimicrobial resistance in aquaculture: a crisis for concern. Biologia, 75(9), 1497. https://doi.org/10.2478/s11756-020-00456-4. Hietala, V., Horsma-Heikkinen, J., Carron, A., Skurnik, M., & Kiljunen, S. (2019). The Removal of Endo- and Enterotoxins From Bacteriophage Preparations. Frontiers in Microbiology, 10. https://doi.org/10.3389/fmicb.2019.01674

Gholami, A., Dowling, J., & Laure, E. (2015, July 20). A security framework for population-scale genomics analysis. *International Conference on High Performance Computing and Simulation*. https://doi.org/10.1109/HPCSIM.2015.7237028

González-Gómez, J. P., Soto-Rodriguez, S. A., Gomez-Gil, B., Serrano-Hernández, J. M., Lozano-Olvera, R., López-Cuevas, O., ... & Chaidez, C. (2023). Effect of phage therapy on survival, histopathology, and water microbiota of Penaeus vannamei challenged with Vibrio parahaemolyticus causing acute hepatopancreatic necrosis disease (AHPND). *Aquaculture*, *576*, 739851.

Hodgson, K. (2013). Bacteriophage therapy. In Microbiology Australia, 28-31.

Hossain, M. M. M., Tanni, L. N., Rahman, M. A., Farjana, N., Moon, R. S., Tonni, N. Z., et al. (2024). Bacteriophage and non-pathogenic Vibrio to control diseases in shrimp aquaculture. Comparative Immunology Reports 6:200126. https://doi.org/10.1016/j.cir.2023.200126.

Howard-Varona, C., Hargreaves, K. R., Abedon, S. T., & Sullivan, M. B. (2017). Lysogeny in nature: mechanisms, impact and ecology of temperate phages. *The ISME Journal*. https://doi.org/10.1038/ISMEJ.2017.16

Huang, K., & Nitin, N. (2019). Edible bacteriophage-based antimicrobial coating on fish feed for enhanced treatment of bacterial infections in aquaculture industry. Aquaculture 502:18–25. https://doi.org/10.1016/j.aquaculture.2019.01.041.

Imbeault, S., Tremblay, D., & Moineau, S. (2006). Bacteriophage therapy: Mechanisms of action and applications. Bacteriophage Research 7(1):45–57.

Islam, G. S., Wang, Q., & Sabour, P. M. (2017). Encapsulation Strategies of Bacteriophage (Felix O1) for Oral Therapeutic Application. Methods in Molecular Biology, 71. https://doi.org/10.1007/978-1-4939-7343-9_6

Jassim, S., & Limoges, R. G. (2014). Natural solution to antibiotic resistance: bacteriophages ‘The Living Drugs’ [Review of Natural solution to antibiotic resistance: bacteriophages ‘The Living Drugs’]. World Journal of Microbiology and Biotechnology, 30(8), 2153. Springer Science+Business Media. https://doi.org/10.1007/s11274-014-1655-7

Jo, A., Ding, T., & Ahn, J. (2016). Synergistic antimicrobial activity of bacteriophages and antibiotics against Staphylococcus aureus. *Food Science and Biotechnology*. https://doi.org/10.1007/S10068-016-0153-0

Joy, J. P. (2021). Exploring the lytic and lysogenic life cycles of bacteriophages. Current Science. https://doi.org/10.24918/CS.2021.6.

Kalatzis, P. G., Castillo, D., Katharios, P., & Middelboe, M. (2018). Review Bacteriophage Interactions with Marine Pathogenic Vibrios: Implications for Phage Therapy

Kaur, S., Kaur, H., Kaur, B., Kumar, B. N., Tyagi, A., Singh, P., et al. (2024). Isolating pathogenic multidrug-resistant Aeromonas hydrophila from diseased fish and assessing the effectiveness of a novel lytic Aeromonas veronii bacteriophage (AVP3) for biocontrol. Microbial Pathogenesis 196:106914. https://doi.org/10.1016/j.micpath.2023.106914.

Kazimierczak, M., Cao, Z., & Hassan, R. (2018). Innovations in aquaculture disease management: The role of phage therapy. Journal of Aquatic Biotechnology 24(8):523–534. https://doi.org/10.1016/j.jab.2018.06.003.

Kumari, M., Singh, R., & Verma, R. (2023). Evaluation of phage therapy against Aeromonas hydrophila infection in Pangasius buchanani. Frontiers in Aquaculture 2:1201466. https://doi.org/10.3389/faquc.2023.1201466.

Kunttu, P., Sundell, K., & Wiklund, T. (2021). Antimicrobial strategies in aquaculture: Challenges and solutions. Pathogens 10(2):99–115. https://doi.org/10.3390/pathogens10020099.

Kusunur, A. B., Mogilipuri, S. S., Moturu, D., Benala, M., Vaiyapuri, M., Panda, S. K., et al. (2023). Tetracycline resistance potential of heterotrophic bacteria isolated from freshwater fin-fish aquaculture system. Journal of Applied Microbiology. https://doi.org/10.1093/jambio/lxad060.

Laanto E, Bamford JK, Ravantti JJ, Sundberg LR. The use of phage FCL-2 as an alternative to chemotherapy against columnaris disease in aquaculture. Front Microbiol. 2015 Aug 19;6:829. doi: 10.3389/fmicb.2015.00829. PMID: 26347722; PMCID: PMC4541368.

Le, S. T., & Kurtböke, İ. 2019. Bacteriophages as biocontrol agents in aquaculture. Microbiology Australia. https://doi.org/10.1071/MA19003.

Liang, J., Wang, Z., & Chen, Y. (2023). Antibiotic resistance genes in aquaculture environments: Occurrence, transfer, and implications. Environmental Microbiology. https://doi.org/10.1111/1462-2920.16345.

Liang, S., Liang, R., Raza, S. H. A., Huang, Q., Li, T., Bai, H., et al. (2025). Biological analysis of phage vB_AhaP_PT2 and treatment rescued crucian carp infected with Aeromonas hydrophila. Aquaculture 595:741654.

Linares, R., Arnaud, C.-A., Degroux, S., Schoehn, G., & Breyton, C. (2020). Structure, function and assembly of the long, flexible tail of siphophages. Current Opinion in Virology. https://doi.org/10.1016/J.COVIRO.2020.06.010.

Liu, R., Han, G., Zong, L., Cun, S., Hao, B., Zhang, J., & Liu, X. (2022). Bacteriophage therapy in aquaculture: current status and future challenges. Folia Microbiologica, 67(4), 573. Springer Science+Business Media. https://doi.org/10.1007/s12223-022-00965-6

Liu, X., Ming, Z., Ding, Y., Guan, P., Shao, Y., Wang, L., & Wang, X. (2025). Characterization of a novel phage SPX1 and biological control for biofilm of Shewanella in shrimp and food contact surfaces. International Journal of Food Microbiology 426:110911. https://doi.org/10.1016/j.ijfoodmicro.2024.110911.

Lomelí-Ortega, C. O., Barajas-Sandoval, D., Ramírez-Sánchez, I., Martínez-Villalobos, J. M., Leptihn, S., & Quiroz-Guzmán, E. (2025). Complete genome sequence of Vibrio diabolicus bacteriophage

vB_Vc_SrVc2 and its efficacy as prophylactic phage therapy. Virology 602:110322.
Los, M. (2020). Strategies of phage contamination prevention in industry. Open Journal of Biology: https://doi.org/10.17352/OJB.000014.
Ly-Chatain, M. H. (2014). The factors affecting effectiveness of treatment in phage therapy. Frontiers in Microbiology. https://doi.org/10.3389/FMICB.2014.00051.
Mateus, L., Costa, L., Silva, Y. J., et al. (2014). Efficiency of phage cocktails in the inactivation of *Vibrio* in aquaculture. *Aquaculture*, 424–425, 167–173. https://doi.org/10.1016/j.aquaculture.2013.12.033.
Misol Jr, G. N., Kokkari, C., & Katharios, P. (2020). Biological and genomic characterization of a novel jumbo bacteriophage, vB_VhaM_pir03 with broad host lytic activity against Vibrio harveyi. Pathogens 9(12):1051. https://doi.org/10.3390/pathogens9121051.
Möller, J., Emge, P., Avalos Vizcarra, I., Kollmannsberger, P., & Vogel, V. (2013). Bacterial filamentation accelerates colonization of adhesive spots embedded in biopassive surfaces. *New Journal of Physics*. https://doi.org/10.1088/1367-2630/15/12/125016.
Morrison, S., & Rainnie, D. J. (2004). Bacteriophage therapy: an alternative to antibiotic therapy in aquaculture?
Muramatsu, H., Lam, K., Bajusz, C., Laczkó, D., Karikó, K., Schreiner, P., Martin, A., Lutwyche, P., Heyes, J., & Pardi, N. (2022). Lyophilization provides long-term stability for a lipid nanoparticle-formulated, nucleoside-modified mRNA vaccine. Molecular Therapy, 30(5), 1941. https://doi.org/10.1016/j.ymthe.2022.02.001
Nguyen, C. D., Amoroso, G., Ventura, T., & Elizur, A. (2020). Assessing the pyloric caeca and distal gut microbiota correlation with flesh color in Atlantic salmon (Salmo salar L., 1758). Microorganisms 8(8):1244. https://doi.org/10.3390/microorganisms8081244.
Ninawe, A. S., Sivasankari, S., Ramasamy, P., Kiran, G. S., & Selvin, J. (2020). Bacteriophages for aquaculture disease control. Aquaculture International 28:1925–1938. https://doi.org/10.1007/s10499-020-00555-3.
Nokhwal, A., Anand, T., Ravikant, & Vaid, R. K. (2023). Bacteriophage therapy: an emerging paradigm in fish disease management. *Aquaculture International*, *31*(2), 777-805.
Oliveira, J. M. M., Castilho, F., Cunha, Â., & Pereira, M. J. (2012). Bacteriophage therapy as a bacterial control strategy in aquaculture. Aquaculture International, 20(5), 879. https://doi.org/10.1007/s10499-012-9515-7
Opperman, C., Sundell, K., & Wiklund, T. (2022). Treating bacterial infections with bacteriophages in the 21st century: Opportunities and challenges. Frontiers in Microbiology 13:654120. https://doi.org/10.3389/fmicb.2022.654120.
Orndorff, P. E. (2016). Use of bacteriophage to target bacterial surface structures required for virulence: A systematic search for antibiotic alternatives. Current Genetics. https://doi.org/10.1007/S00294-016-0603-5.
Park, S. C., & Nakai, T. (2003). Bacteriophage control of Pseudomonas plecoglossicida infection in ayu Plecoglossus altivelis. Diseases of Aquatic Organisms 53(1):33–39. https://doi.org/10.3354/dao053033.
Peña-Rodríguez, A., Ramírez-Sánchez, I., Leptihn, S., & Quiroz-Guzmán, E. (2025). A novel vibriophage vB_Vp_PvVp04 against pathogenic Vibrio parahaemolyticus and its formulation for inclusion in shrimp feed. Aquaculture International 33(1):117. https://doi.org/10.1007/s10499-024-01012-4.
Pereira, A., Silva, J., & Gomes, D. (2022). Advances in aquaculture: Emerging technologies and sustainable practices. Aquaculture Journal 15(3):123–135. https://doi.org/10.1007/s10499-022-01002-7.
Pereira, C., Silva, Y. J., Santos, A. L., Cunha, A., Gomes, N. C. M., & Almeida, A. (2011). Bacteriophages with potential for inactivation of fish pathogenic bacteria: Survival, host specificity and effect on bacterial community structure. Marine Drugs. https://doi.org/10.3390/MD9112236.
Pirnay, J.-P., Blasdel, B. G., Bretaudeau, L., Buckling, A., Chanishvili, N., Clark, J. R., Côrte-Real Sofia, V., Debarbieux, L., Dublanchet, A., De Vos, D., Gabard, J., Garcia, M., Goderdzishvili, M., Górski, A., Górski, A., Hardcastle, J., Huys, I., Kutter, E., Lavigne, R., … Van den Eede, G. (2015). Quality and Safety Requirements for Sustainable Phage Therapy Products. *Pharmaceutical Research*. https://doi.org/10.1007/S11095-014-1617-7
Platt, R. (2000). *Bacteriophage therapy: a novel method of lytic phage delivery*. https://doi.org/10.31274/RTD-180813-15276
Rai, S., Kaur, B., Singh, P., Singh, A., Benjakul, S., Reddy, S., Nagar, V., & Tyagi, A. (2023). Perspectives on phage therapy for health management in aquaculture. Aquaculture International, 32(2), 1349. https://doi.org/10.1007/s10499-023-01220-6
Ramírez, C., & Romero, J. (2024). Unveiling hidden allies: In silico discovery of prophages in Tenacibaculum species. Antibiotics 13(12):1184. https://doi.org/10.3390/antibiotics13121184.
Ren, H., Li, Z., Xu, Y., Wang, L., & Li, X. (2019). Protective effectiveness of feeding phage cocktails in controlling Vibrio parahaemolyticus infection of sea cucumber Apostichopus japonicus. *Aquaculture*. https://doi.org/10.1016/J.AQUACULTURE.2019.01.006
Richards, G. P. (2014). Bacteriophage remediation of bacterial pathogens in aquaculture: a review of the

technology. Bacteriophage, 4(4). Taylor & Francis. https://doi.org/10.4161/21597081.2014.975540.
Rocha, C., Cabral, H. N., Marques, J. C., & Gonçalves, A. M. M. (2022). A global overview of aquaculture food production with a focus on the activity's development in transitional systems—The case study of a South European country (Portugal). Journal of Marine Science and Engineering. https://doi.org/10.3390/jmse10030417.
Romero, J., Alvial, A., Duran-Avelar, M. de J., Rivas, A., & Bastías, R. (2024). Lysin and lytic phages reduce Vibrio counts in live feed and fish larvae. *Microorganisms*, *12*(4), 831. https://doi.org/10.3390/microorganisms12040831.
Royam, M. M., & Nachimuthu, R. (2020). Isolation, characterization, and efficacy of bacteriophages isolated against Citrobacter spp.: An in vivo approach in a zebrafish model (Danio rerio). Research in Microbiology 171(8):341–350. https://doi.org/10.1016/j.resmic.2020.06.002.
Scarano, C., Piras, F., Virdis, S. G., Ziino, G., Nuvoloni, R., Dalmasso, A., De Santis, E. P. L., & Spanu, C. (2018). Antibiotic resistance of Aeromonas spp. strains isolated from Sparus aurata reared in Italian mariculture farms. International Journal of Food Microbiology. https://doi.org/10.1016/j.ijfoodmicro.2018.07.033.
Schulz, P., Pajdak, J., & Siwicki, A. K. (2022). In Vivo Bacteriophages' Application for the Prevention and Therapy of Aquaculture Animals–Chosen Aspects [Review of In Vivo Bacteriophages' Application for the Prevention and Therapy of Aquaculture Animals–Chosen Aspects]. Animals, 12(10), 1233. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/ani12101233.
Sieiro, C., Areal-Hermida, L., Pichardo-Gallardo, Á., Almuiña-González, R., de Miguel, T., Sánchez, S., Sánchez-Pérez, A., & Villa, T. G. (2020). A hundred years of bacteriophages: Can phages replace antibiotics in agriculture and aquaculture? The Journal of Antibiotics. https://doi.org/10.3390/antibiotics9080493.
Stenholm, A. R., Dalsgaard, I., & Middelboe, M. (2008). Isolation and characterization of bacteriophages infecting the fish pathogen Flavobacterium psychrophilum. Applied and environmental microbiology, 74(13), 4070-4078.
Sundberg, L., Sundell, K., & Wiklund, T. (2021). Role of bacteriophages in aquaculture: Potential and challenges. Microbial Biotechnology 13(6):1589–1599. https://doi.org/10.1111/1751-7915.13645.
Sundell, K., Landor, L., Castillo, D., Middelboe, M., & Wiklund, T. (2020). Bacteriophages as biocontrol agents for Flavobacterium psychrophilum biofilms and rainbow trout infections. Phage 1(4):198–204. https://doi.org/10.1089/phage.2020.0017.
Torres-Barceló, C., Gurney, J., Gougat-Barbera, C., Vasse, M., Hochberg, M. E., & Hochberg, M. E. (2018). Transient negative effects of antibiotics on phages do not jeopardise the advantages of combination therapies. *FEMS Microbiology Ecology*. https://doi.org/10.1093/FEMSEC/FIY107.
Türe, M., & Alp, H. (2016). Identification of bacterial pathogens and determination of their antibacterial resistance profiles in some cultured fish in Turkey. *Journal of Veterinary Research*, *60*(2), 141-146.
Vincent, A. T., & Charette, S. J. (2022). To be or not to be mesophilic, that is the question for Aeromonas salmonicida. Microorganisms 10(2):240. https://doi.org/10.3390/microorganisms10020240.
Wang, J., Feng, Y., Qin, Z., Geng, Y., Huang, X., Ouyang, P., ... & Lai, W. (2022). Isolation, characterization and complete genome sequencing of a Streptococcus dysgalactiae associated with cultured channel catfish mortalities in China. Aquaculture Reports 27:101408. https://doi.org/10.1016/j.aqrep.2022.101408.
Wong, Z. C., Alwie, N. A. M., Lim, L. S., Sano, M., & Lal, M. T. M. (2024). Potential biocontrol for bacterial and viral disease treatment in aquaculture: A minireview. Journal of Microorganism Control 29(3):99–103.
Yaşa, İ., Evran, S., Eren Eroğlu, A. E., Önder, C., Allahyari, M., Menderes, G., & Kullay, M. (2024). Partial characterization of three bacteriophages isolated from aquaculture hatchery water and their potential in the biocontrol of Vibrio spp. Microorganisms 12(5):895. https://doi.org/10.3390/microorganisms12050895.
Ye, M., et al. (2019). Environmental impacts of phage therapy: A review. Environment International.
Yılmaz, D. K., & Berik, N. (2025). Phenotypic and Genotypic Antibiotic Resistance of Bacteria Isolated from Ready-to-eat Salted Seafood. *Aquatic Sciences and Engineering*, *40*(1), 9-17.
Zhang, L., Zhao, H., & Liu, J. (2021). Environmental persistence of antibiotics and antibiotic resistance genes in aquaculture systems. Environmental Science & Technology 12(5):467–479.
Zhang, X., Klümper, U., Krömeke, J., Hille, F., Meeske, A. J., & Smits, S. H. J. (2022). CRISPR–Cas9 based bacteriophage genome editing. *Microbiology Spectrum*, *10*(6), e00820-22. https://doi.org/10.1128/spectrum.00820-22

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

Şabut balığının (*Arabibarbus grypus* Heckel, 1843) Lipit Sağlık ve Besin Kalite İndeksleri Değerlendirmesi: Uluçay Suyu (Siirt) Örneği

Ramazan Bozkurt[1]* A. Yusuf Yüksel[2] Muhammed Yaşar Dörtbudak[1]

Özet: Şabut balığı (*Arabibarbus grypus* Heckel, 1843), Siirt yöresinde beğenilerek tercih edilen bir balık türüdür. Balıkçılardan alınan örneklerdeki hesaplamalar, kas dokularının yağ asidi verilerine dayanarak yapılmıştır. İnsan sağlığına yararlı h/H, %2.65-2.71; sağlığı geliştiren indeks HPI, %2.82-4.23 ve besleyici değer indeksi BDİ (NVI) ise %1.93-2.05 arasında olduğu kaydedilmiştir. Balığın profil indeks değeri PI %6.28, Fulton katsayısı (FC) %1.23; kalite indeks (Kiselev) değeri QI ise %2.04 olarak belirlenmiştir. TI (kalınlık indeksi) %78.52, FI (fleshy) indeksi ise %20.06 olarak hesaplanmıştır. Ocak-Kasım aylarındaki (2023) doymuş yağ asidi (SFA) %23.82-%34.53; tekli doymamış yağ asidi MUFA %45.96 - %51.49 ve çoklu doymamış asidi (PUFA) ise %22.63- %30.50 arasında değişkenlik göstermiştir. Tüm yıldaki Omega n3/n6 ortalaması 1.33'tür. Sanojenik indeks değerlerinden AI (Aterojenik indeks) %0.40–0.45 ve TI (Trombojenik indeks) ise %0.35 – 0.42 arasında olduğu tespit edilmiştir. Çalışma sonuçlarına göre Şabut balığı *(A.grypus*), insan sağlığı açısından yarayışlı olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Şabut, lipit kalitesi, besin kalitesi, Omega-3, sağlık indeksi

Assessment of Lipid Health and Food Quality Indices of Shabut Fish (*Arabibarbus grypus* Heckel, 1843): The Sample of Uluçay Stream (Siirt)

Abstract: Shabut fish (*Arabibarbus grypus* Heckel, 1843) is a popular and preferred fish species in Siirt region. The estimates in the samples taken from the fishermen were based on the fatty acid data of the muscle tissues. It was determined that H/H, beneficial for human health, was between 2.65-2.71%; HPI, health promoting index, was between 2.82-4.23% and NVI, nutritive value index, was between 1.93-2.05%. The profile index value PI of the fish was 6.28%, Fulton coefficient (FC) was 1.23% and quality index (Kiselev) value QI was 2.04%. TI (thickness index) was calculated as 78.52% and FI (fleshy) index as 20.06%. Saturated fatty acid (SFA) in January-November (2023) varied between 23.82%-34.53%, monounsaturated fatty acid MUFA between 45.96%-51.49% and polyunsaturated fatty acid (PUFA) between 22.63%-30.50%. Omega n3/n6 mean for the whole year was 1.33. Sanogenic index values of AI (Atherogenic index) and TI (Thrombogenic index) were found to be between 0.40-0.45% and 0.35-0.42%, respectively. The results of the study concluded that Shabut fish (*A.grypus*) is beneficial for human health.

Keywords: Shabut, lipid quality, food quality index, omega-3, health index

Makale Bilgisi (Araştırma)

1 Harran Üniversitesi, Organize Sanayi Bölgesi Meslek Yüksekokulu, Gıda İşleme Bölümü, 63100, Şanlıurfa, Türkiye
2 Harran Üniversitesi, Bozova Meslek Yüksekokulu, Balıkçılık ve Su Ürünleri Yetiştiriciliği Bölümü, 63850, Şanlıurfa, Türkiye
***Sorumlu yazar:** bozkurtr63@gmail.com

Alıntı: Bozkurt, R., Yüksel, A.Y., Dörtbudak, M.Y. (2025). Şabut balığının (*Arabibarbus grypus* Heckel, 1843) Lipit Sağlık ve Besin Kalite İndeksleri Değerlendirmesi: Uluçay Suyu (Siirt) Örneği, MEMBA Su Bilimleri Dergisi. 11 (2), 201-211.
https://doi.org/10.58626/memba.1728318

Başvuru Tarihi: 30 Ocak 2025
Kabul Tarihi: 16 Mayıs 2025
Yayın Tarihi: 28 Haziran 2025

1. Giriş

Protein ve omega gibi zengin yağ asitlerini içeren balıklar hem besin değeri hem de tıbbi katkılarının belirlenmesi açısından insan vücuduna yararlı fonksiyonel bileşenler içerirler (Łuczyńska vd., 2023; Taşbozan ve Gökçe, 2017). İnsan sağlığı için önem kazanmaya başlayan FC (Fulton katsayısı), QI (kalite indeksi) ve BDİ (besleyici değer indeksi, NVİ) gibi indeksler, çeşitli pişirme yöntemleriyle de karşılaştırılmıştır (Çaklı vd., 2023; Haq vd., 2025; Łuczyńska vd., 2023). Lipit profilindeki n3 çoklu doymamış asidi (PUFA)'ların yanı sıra, sağlığı geliştirici sanojenik indekslerden HUFA (yüksek doymamış yağ asidi), AI (Aterojenik indeks), TI (Trombojenik indeks), h/H (Hipokolesterolemik/Hiperkolesterolemik), HPI (sağlık geliştirici indeks) hakkında da çalışmalar yapılmıştır (Ahmed vd., 2022; Aysondu vd., 2022; Özer vd., 2022). Yapılan birçok çalışmada, PUFA, Aİ, AT ve h/H gibi sanojenik indeks kaynağı bakımından zengin olan deniz ürünlerinin tercih edilmesi önerilmiştir. Balıklardaki sanojenik indeksler, kardiyovasküler (KVK), diyabet, kanser, cilt, alzheimer, beyin, sinir dokusu ve gastrit kökenli semptomlar için yarayışlı olduğu ifade edilmiştir (Cholidis vd., 2024; Srıvastava, 2025). Balıklardaki etlilik (FI), FC, QI ve kalınlık indeks (TI) oranları, fonksiyonel gıda bakımından değer kazanmıştır (Nistor vd., 2014; Simeanu vd., 2022). İnsan sağlığı açısından tatlı su ve deniz balıklarındaki omega n3/n6 PUFA oranlarının asgari 1 olmasında yarar vardır. Bu oranlar, çalışılan sulara göre kıyaslanacak olursa tatlı su balıklarında 0.5-3.8; deniz balıklarında ise ortalama 4.7-14.4 arasındadır (Bayar vd., 2021; Henderson ve Tocher, 1987; Jung vd., 2025; Taşbozan ve Gökçe, 2017).
Şabut (*Arabibarbus grypus*) balıkları, Fırat-Dicle havzasında yaşayan ve doğal ortamdaki yemlerden iyi biçimde yararlanma kabiliyeti olan bir türdür. Devlet su işleri (DSİ), ekonomik değerinden dolayı ülkemizin Güneydoğu bölgesindeki birçok baraj gölü ve çevresine her yıl yüzbinlerce yavru bırakmaktadır. Bu sistem üzerinde suyun fiziko-kimyasal kalitesi (Kutlu vd., 2015); mitokondriyal DNA yapıları (Parmaksız, 2016; Parmaksız ve Şeker, 2018; Parmaksız, 2023); ağır metal birikimleri (Dinç ve Dörtbudak, 2020); meristik ve morfometrik özellikler (Ozcan, 2020); balık boyu-otolit boyutları (Başusta ve Girgin, 2023) gibi çalışmalar mevcuttur. Şabut (*A. grypus*) balığının yağ asitleri hakkında (Bozkurt vd., 2024; Doğu vd., 2014; Gokce vd., 2011; Güllü et al 215; Kaçar ve Başhan, 2022; Parlak vd., 2015; Yakar vd., 2023) araştırmalar yapılmıştır. *Arabibarbus grypus*'lar için yapılan çalışmalarda ARA/EPA, FLQ, HPI, DFA ve BDİ (NVİ) gibi beslenme indeks değerlerini kapsayan çalışmaların yetersiz olduğu saptanmıştır. Bu çalışmaki amaç, daha önce yapılmayan Şabut balığının besin kalite indeks verileri ile bazı sağlık indeks değerlerinin tespit edilmesidir.

2. Materyal ve Metod

Dicle nehrinin kollarından Uluçay suyu (Botan suyu-Siirt), Bitlis deresiyle birleştikten sonra Dicle nehrine dökülmektedir. Örnekler, Ocak, Mart, Eylül ve Kasım (2023) aylarında, Uluçay suyu kesiminde ticari olarak satış yapan balıkçılardan, her ayı temsil eden 10'ar adetten toplam 40 adet dişi balık numunesi seçilerek satın alınmıştır. Numuneler, satın alma noktasından laboratuvara içi buz dolu termoslara yerleştirilerek taşınmıştır. Laboratuvara getirilen örnekler, -25 °C'deki derin dondurucuda saklanmıştır.

2.1. Şabut balıklarının yağ asitleri analizi

Analiz işlemlerine geçmeden önce balık örnekleri temizlenmiştir. Analiz için başın arkası ile sırtı arasında kalan kısımdaki kaslar alınmıştır. Yağ asitleri analizlerinin belirlenmesi işlemlerinde kloroform/metanol eriyiği (2:1 v/v) tercih edilmiştir (Folch vd., 1957). Metillendirmelerde, TS EN ISO 12966:2 (Ciobanu vd., 2019; Yakar vd., 2023) metoduyla takriben 100 mg yağ örneği 10 mL şeklindeki deney tüplerine aktarılmıştır. Ağırlıkları ölçüldükten sonraki işlemler için tüplere 2 mL civarında izooktan 100 µL konulan numuneler, vortekslenmiştir. Ortalama 1 dakikalık zaman periyodundan sonra numunelere yaklaşık 2 mL %40'lık NaCl solüsyonu eklenmiş ve tekrar karıştırılmıştır. Şişe içerisindeki İzooktan çözeltisi, 1 g sodyum bisülfat kimyasalıyla tekrar karıştırılmıştır. 30 dakika saat sonra, *A. grypus* balık numunelerinin yüzeyinde ince bir şırıngayla 1 µL kadarlık çözelti alınmış ve Gaz Kromatografisi (GC) içerisine aktarılmıştır. Analiz işlemlerinde, yağ asidinin metil esterlerine (FAME) dönüşümü yapıldıktan sonraki işlemlerde 40-50 dakikalık bir süre geçtikten sonra GC sistemiyle sürdürülmüştür. *A. grypus*'ların analizlerinde Thermo-Trace GC modeli tercih edilmiştir. Çözücüdeki karışımlar, 60 m HP-88 kılcal kolonuyla hazırlanarak, sıcaklığı yaklaşık 280°C ile 250°C şeklinde düzenlenmiştir. Kolon içerisindeki sıcaklıklar periyodik olarak sırasıyla 50, 20, 180 ile 230°C'ye yükseltilmiştir. Sıcaklık periyodu yaklaşık 2, 20 ve 5 °C/dk yükselişle 230 °C kadar sıcaklığa çıkarılmıştır. Bu sıcaklıkta, ortalama 5,5 dk kadar dinlendirilmiştir. Bölünme ölçekleri 1/50 şeklindedir. Çalışmada, 1 µL'lik şırınga kullanılmıştır (Yakar vd., 2023).

2.2. Lipit sağlık ve vücut indeks katsayısı formülleri

Balıklarla ilgili yapılan biyometrik çalışmalardaki metrik ve gravimetrik (ağırlık) hesaplamalar, balıklarla ilgili

önemli veriler verir (Simeanu vd., 2022).
Çalışmada, balıklar için hesaplanan bedensel indeks formülleri ve referansları verilmiştir.

$$PI = I/H \quad (1)$$

PI = Profil indeksi, (Egessa vd., 2024; Nistor vd., 2012).

$$FC = (m * 100)/I^3 \quad (2)$$

FC = Fulton katsayısı, (Aydın vd., 2024; Egessa vd., 2024).

$$QI = I/C \quad (3)$$

QI = Kalite indeksi (Kiselev), (Liang vd., 2024).

$$TI = (T/H) * 100 \quad (4)$$

TI = Kalınlık indeksi, (Uiuiu vd., 2017).

$$FI\ (Ic) = (lh/l) * 100 \quad (5)$$

FI= Etlilik indeksi, (Magdici vd., 2014).

Biyometrik ölçülerde I= Standart uzunluk, (cm); H= Vücut yüksekliği (cm); m= Ağırlık (g); C = Vücut çevresi (cm); T= Vücut kalınlığı (cm); lh= Baş uzunluğu (cm).

2.3. Lipit sağlık ve besleyici kalite indeks formülleri

$$AI = ((C12{:}0) + (4 \times C14{:}0) + (C16{:}0))/((\Sigma MUFA) + (\Sigma PUFA) \quad (6)$$

AI: Aterojenik indeks, (Çaklı vd., 2023; Ulbricht & Southgate, 1991).

$$TI = ((C14{:}0) + (C16{:}0) + (C18{:}0))/((0.5 \times MUFA) + (0.5 \times n6\ PUFA) + (3 \times n3\ PUFA) + (n3/n6)) \quad (7)$$

TI: Trombojenik indeks , (Bengü, 2024; Ulbricht & Southgate, 1991).

$$h/H = ((C18{:}1n9) + PUFA)/((C12{:}0 + C14{:}0 + C16{:}0)) \quad (8)$$

h (Hipokolesterolemik)/H (Hiperkolesterolemik), (Chen vd., 2016; Đuričić vd., 2022).

$$DFA = UFA(MUFA + PUFA) + C18{:}0 \quad (9)$$

DFA: Arzu edilen yağ asidi, (Chen vd., 2016; Senso vd., 2007).

$$OFA = C12{:}0 + C14{:}0 + C16{:} \quad (10)$$

OFA (H): Hiperkolesterolemik, (Đuričić vd., 2022).

$$PI = ((C18{:}2\,n-6) + (C18{:}3\,n-3 \times 2) \quad (11)$$

PI: Balıketinin çoklu doymamışlık indeksi, (Simeanu vd., 2022).

$$HPI = UFA\ /(C12{:}0 + C14{:}0 + C16{:}0) \quad (12)$$

HPİ: Sağlığı geliştiren indeks, (Bengü, 2024; Chen vd., 2004).

$$EFA = C18{:}2 + C18{:}3 + C20{:}4 \quad (13)$$

EFA: Esansiyel yağ asitleri, (Đuričić vd., 2022).

$$HUFA = EPA + DH. \quad (14)$$

HUFA (EPA + DHA): Yüksek doymamış yağ asidi, (Çaklı vd., 2023).

$$FLQ = (C20:5\,n3 + C22:6\,n3\,/total\,FA) * 100 \qquad (15)$$

FLQ: Et-lipit kalite indeksi (flesh- lipit quality), (Dernekbaşı vd., 2021; Erdem ve Dinçer, 2023).

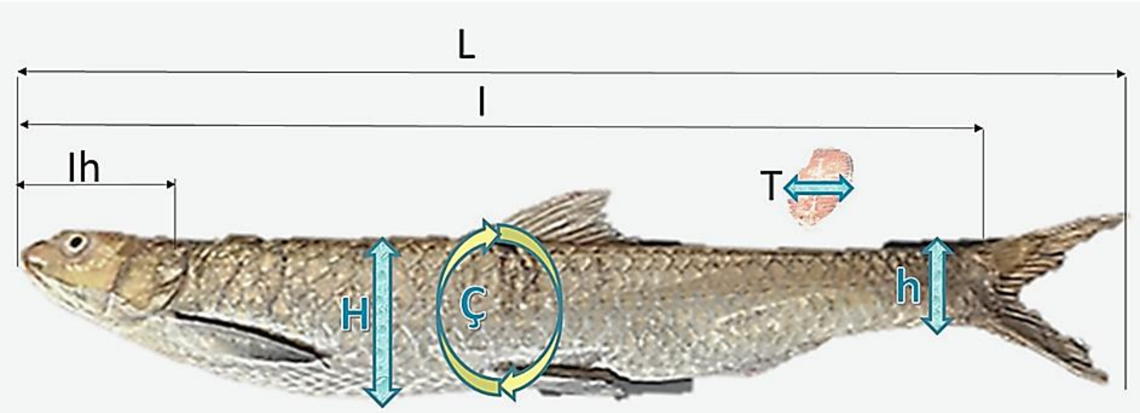
$$BDİ\,(NVI) = (C18:0 + C18:1)\,/\,(C16:0) \qquad (16)$$

BDİ: Besleyici değer indeksi (NVİ, nutritive value index), (Zula ve Desta, 2021).

Elde edilen yağ asit verileri, ortalama ± standart sapma (%) şeklinde hesaplanmıştır (Özbek ve Keskin, 2007). Balık örneklerinde, grup verileri arasındaki farklılıkların anlamsal düzeylerinin ($p<0.05$) belirlenmesinde tek yönlü ANOVA- SPSS kullanıldı.

3. Bulgular ve Tartışma

Arabibarbus grypus balıklarındaki biyometrik indeks hesaplamaları, et-lipit kalitesi ile birlikte bazı beslenme indekslerini de ortaya çıkarmıştır. Şekil 1 ve Denklem (1-16)'ya göre Şabut balığının bedensel indeks, etin lipid kalitesi ve balıklardaki besleyici değer indeksinin hesaplama formülleri verilmiştir.



Şekil 1. Uluçay suyunda yaşayan Şabut balığı (*Arabibarbus grypus* Heckel, 1843). L= Toplam uzunluk, l= Standart uzunluk, (cm); H= Vücut yüksekliği (cm); h—Vücut minimum yüksekliği (cm); Ç = Vücut çevresi (cm); T= Vücut kalınlığı (cm); lh= Baş uzunluğu (cm).

3.1. Morfometrik ve vücut indeksleri

Balıkların bazı ortalama biyometrik (n=40, boy=55, 54cm, ağırlık=2031g), profil, beslenme ve diğer vücut indeks değerleri hesaplanmıştır (Çizelge 1) (Cengiz vd., 2024; Gökçe vd., 2011; Parlak vd., 2015). Şekil 1'e göre hesaplanan şabut balığının (*A. grypus*) biyometrik indeks değerleri Çizelge 1'de verilmiştir.

Çizelge 1. Şabut balığının (*A.grypus*) bazı biyometrik ölçümleri ile vücut indeksleri hesaplaması.

Biyometrik özellikler	Ortalama ± *SD*
Vücut ağırlığı (g), (min. - max.)	2031±858.71 (930-4070)
Standart uzunluk (cm), (min.-max.)	55.54±11.79 (33-75)
Baş uzunluğu (cm), (min. - max.)	10.99±2.24 (8-13)
Maksimum vücut yüksekliği (cm), (min. - max.)	8.87±2.00 (6-11)
Maksimum vücut çevresi (cm), (min. - max.)	25.525±5.28 (19-39)

Gövdenin maksimum kalınlığı (cm), (min. - max.)	7.07±2.10 (3.5-11.5)
Vücut İndeks ve Katsayıları	
Pİ = Profil indeksi	6.28±0.48
FC= Fulton katsayısı	1.23±0.46
QI = Kalite indeksi (Kiselev)	2,17±0.16
TI= Kalınlık indeksi	79.52±14.06
FI = Etlilik indeks	20.06±3.16

3.2. Lipit sağlık kalite indeksleri

Örneklerin sırt kasından alınan numunelerdeki yağ asitlerinin aylara göre değişimleri Çizelge 2'de verilmiştir.

Çizelge 2. Şabut balığının *(A. grypus)* örneklerinde, 2023 yılı aylarına göre 20 çeşit lipit profil ve sanojenik indeks değerleri hesaplanmıştır (%)*.

Yağ Asitleri	Ocak	Mart	Eylül	Kasım
(C12:0) Laurik Asit	**	**	**	0.16±0.05^{a}
(C14:0) Miristik Asit	2.25±0.15 ^{b}	1.97±0.06^{a}	3.54±0.05^{c}	2.02±0.08^{a}
(C15:0) Pentadekanoik Asit	0.25±0.08 ^{a}	0.44±0.05^{b}	0.90±0.06^{c}	0.27±0.07^{a}
(C16:0) Palmitik Asit	16.97±0.06^{a}	18.74±0.17 ^{b}	22.88±0.09^{c}	19.95±0.19^{d}
(C17:0) Heptadekanoik Asit	0.38±0.12 ^{a}	0.89±0.09 ^{b}	0.87±0.07^{b}	0.40±0.06^{a}
(C18:0) Stearik Asit	3.24±0.19 ^{a}	5.31±0.09 ^{c}	4.96±0.09^{b}	5.91±0.09^{d}
(C20:0) Araşidik Asit	0.32±0.07 ^{a}	0.39±0.08 ^{a}	0.51±0.05^{b}	0.28±0.07^{a}
(C22:0) Behenik Asit	0.31±0.06 ^{a}	0.46±0.08^{b}	0.87±0.08^{c}	0.35±0.07^{a}
Toplam Doymuş Yağ Asidi (SFA)	23.82±0.27^{a}	28.21±0.21^{b}	34.53±0.50^{c}	29.34±0.67^{b}
(C14:1) Miristoleik Asit	0.25±0.08^{b}	0.20± 0.08 ^{ab}	0.29±0.04^{bc}	0.17±0.07 ^{a}
(C16:1) Palmitoleik Asit	4.64±0.18 ^{b}	6.99±0.09^{c}	8.85±0.09^{d}	3.73±0.08^{a}
(C17:1) cis-10-Heptadekenoik Asit	0.47±0.17^{b}	0.93±0.09^{c}	0.89±0.07^{c}	0.23±0.12^{a}
C18:1n9c) Oleik asit	29.48±0.21	30.90±0.16	39.99±0.07^{c}	35.05±0.09^{b}
(C20:1n9) cis-11-Eikosenoik Asit	0.80±0.06 ^{a}	1.01±0.09^{b}	0.94±0.05^{b}	0.69±0.09^{a}
(C24:1n9 Nervonik Asit)	0.32±0.07^{a}	0.83±0.09^{d}	0.53±0.09c	0.42±0.08^{b}
Toplam Tekli Doymamış Yağ Asidi(MUFA)	35.95±0.28^{a}	40.85±0.25^{b}	51.49±0.42^{c}	40.28±0.54^{b}
(C18:3n3) A-Linolenik Asit	2.31±0.05 ^{b}	2.05±0.08^{a}	2.95±0.05^{c}	3.88±0.07^{d}
(C20:5n3) Eikosapentaenoik Asit (EPA)	1.91±0.04^{a}	3.08±0.0b^{b}	3.93±0.06^{c}	2.84±0.07^{b}
(C22:6n3) Dokosaheksaenoik Asit (DHA)	6.96±0.06 ^{a}	10.25±0.19^{b}	11.83±0.09^{c}	6.66±0.17^{a}
n3	11.18±0.06^{a}	15.38±0.15^{c}	18.71±0.20^{d}	13.38±0.32^{b}
(C18:2n6c) Linoleik Asit	7.74±0.07^{b}	7.08±0.16^{a}	8.91±0.08^{d}	8.02±0.07^{c}
(C20:2) Eikosadienoik Asit	0.28±0.08^{ab}	0.29±0.13^{b}	0.32±0.05^{b}	0.20±0.06^{a}
(C20:4n6) Araşidonik Asit	3.43±0.13^{d}	3.23±0.19^{c}	2.56±0.08^{b}	2.00±0.07^{a}
n6	11.45±0.22^{c}	10.59±0.29^{b}	11.79±0.21^{d}	10.22±0.12^{a}
PUFA	22.63±0.11^{a}	25.98±0.09^{b}	30.50±0.04^{c}	23.60±0.08^{ab}
HUFA (EPA + DHA)	8.87±0.02^{a}	13.33±0.08^{c}	15.76±0.03^{d}	9.50±0.07^{b}
PUFA/SFA	0.95±0.42^{d}	0.92±0.46^{c}	0.88±0.02^{b}	0.80±0.30^{a}
n3/n6	0.98±0.02^{a}	1.45±0.04^{c}	1.59±0.02^{d}	1.31±0.02^{b}
Tüm sezonun n3/n6 ortalaması	1.33			

*Satırlardaki veriler, ortalama ± SD değerleridir. Aynı sıra üzerinde yer alan aynı karakterlerin istatiksel olarak önemi bulunmamaktadır. ($p<0.05$). AI (Atherojenik Index), TI (Thrombogenic Index). Aynı satırda a,b,c ve d gibi farklı harflerle gösterilen değerler, istatistiksel olarak birbirinden farklıdır ($p<0.05$). **Tanımlanamayan (Unidentified) değerler.

Çizelge 2'ye göre Lipitlerde 20 çeşit yağ asitleri ile sanojenik indeks verileri aylara göre hesaplanmıştır. . Metabolizma ve dolaşım sisteminin sağlıklı çalışmasında Aterojenik (AI) ve Trombojenik (TI) indeks değerleri, PUFA/SFA'ya göre daha çok ilgi çekmiştir (Negara vd., 2021; Păsărin vd., 2023). Yağ asitleri analizlerindeki Oleik ile Palmitik asit miktarları, tüm aylardaki diğer yağ asidi miktarlarından yüksek çıkmıştır (Çizelge 2). Tüm aylardaki n3/n6 ortalaması 1. 33 olarak hesaplanmıştır.

3.3. Şabut balığının (*A. grypus*) beslenme indeksleri

Balıkların gıda değeri açısından değerli olmasının bir nedeni de beslenme indekslerinin verimliliğidir. Beslenme indeksleri Çizelge 3'te verilmiştir.

Çizelge 3. Şabut balığının (*A. grypus*) lipit beslenme endeksleri (Ortalama ±SD).

Beslenme indeksleri - Nutritional indices	Ortalama ±SD
AI	0.43±0.02
TI	0.38±0.03
h/H: Hipokolesterolemik/Hiperkolesterolemik	2.69±0.04
ARA/EPA: Araşidonik asit/EPA: Büyüme performansı	1.05±0.53
PUFA/SFA	0.89±0.06
PUFA/ (SFA -STEARİK ASİT)	1.07±0.06
UFA/SFA: Toplam doymamış yağ asidi / Toplam doymuş yağ asidi	2.34±0.12
PI: Balıketinin çoklu doymamışlık indeksi (Polyunsaturation index of fish meat)	13.53±2.13
UFA (MUFA+PUFA): Toplam doymamış yağ asidi (Total unsaturated fatty acid)	67.82±10.04
h: hipokolesterolemik	59.53±7.81
OFA: Hiperkolesterolemik	22.12±3.10
DFA: Arzu edilen yağ asidi	72.67±10.49
HPİ: Sağlığı Geliştiren İndeks	3.05±0.17
BDİ: Besleyici değer endeksi, NVİ	1.97±0.06
EFA: Esansiyel yağ asitleri	13.54±0.88
FLQ: Et - Lipid kalite indeksi	12.13±1.93

Beslenme İndeksleri (%). Ortalama±SD. SD (Ortalamanın standart sapması).

Çizelge 3'e göre sağlığı geliştiren indeks HPİ ve h/H değerleri hesaplanmıştır. Balık örneklerindeki temel vücut endeks ve katsayılarından Profil indeks ortalaması (PI) %6.28, Gökkuşağı alabalığında ise %3.89 (Nistor vd., 2012) gelmiştir. Balıklar için PI'in %5 dolayında olması, kaliteli bir gelişimin olduğunu gösterir (Simeanu vd., 2022). Bir canlının iştahını ve aldığı gıdaların kondisyonunu bilmek için hesaplanan vücut besilik değeri FC (Fulton katsayısı), *A.grypus*'ta 1.23; *S. triostegus*'ta 0. 99 (dişi) - 0.96 (erkek) (Karadede ve ark, 2004); *S. glanis*'te 0.82 (Simeanu vd., 2022) ve *C. gariepinus'ta* ise ortalama 0.71 (Özcan vd.. 2024) olarak bulunmuştur. Etlilik veya karnozite indeksi FI (Fleshy indeks) %20.06; TI (Kalınlık indeksi) ise %79.50 olarak belirlenmiştir. FI (etlilik indeksi) değerinin %20 dolaylarında çıkması, balığın hem etli hem de yağlı olduğunu göstermiştir (Bektas vd., 2020; Uıuıu vd., 2017). EPA miktarı, Ocak ayından (%1.91) Eylül'e doğru (%3.93) artış göstermiştir ($p<0.05$). DHA, Eylülde %11.83 seviyesinden Kasım'da %6.66 seviyesine kadar düşmüştür ($p<0.05$). PUFA değerleri, Ocak ayından (%22.63) Eylül ayına doğru artmıştır (%30.50) ($p<0.05$). Atatürk barajında PUFA miktarı %19.2 - %26.1 (Gökçe vd., 2011); Keban barajında ise %22.63-%41.11 arasında olduğu saptanmıştır (Parlak vd., 2014). PUFA/SFA miktarları %0.80 – %0.95 arasında değişim göstermiştir ($p<0.05$). n3/n6 oranları, Ocak'tan Eylül'e doğru artmıştır (0.98-1.59). n3/n6, Atatürk barajında 2.4 – 4.8 (Gökçe vd., 2011); Keban barajında ise %0.25- 0.39 arasında gerçekleşmiştir ($p<0.05$). Toplam MUFA'nın (tekli doymamış yağ asitleri), toplam SFA'dan (doymuş yağ asitleri) yüksek çıktığı tespit edilmiştir (Özçiçek vd., 2024). Çalışmamızdaki en fazla yağ asitleri sıralamasında oleik, palmitik, linoleik, DHA ve stearik asit çıkmıştır. Bir çok balıktaki yağ asitleri sıralaması, yaklaşık bu sıralama içerisinde olduğu belirlenmiştir (Ainiwaer vd., 2024; Parlak vd., 2014). Balıklardaki yağ asidi miktarlarının uzun süre muhafaza edilmesinde, suyun fiziko-kimyasal parametrelerindeki değişkenlik de etkilidir. Yaşamını suda sürdüren balıkların çoğalması, beslenmesi ve yağlanmaları, sudaki besinlerin kalite ve miktarlarına da bağlıdır (Kandemir & Polat, 2007). İnsan sağlığına faydalı olan yağ asidi hesaplamalarındaki TI, AI, h/H, Pİ ve BDI gibi beslenme indeks değerlerinin bilinmesi, kayda değer önem taşımaktadır (Łuczyńska vd., 2023; Mgbechidinma vd., 2023). İnsan sağlığı açısından TI'in 0.5'ten düşük, h/H ve kolesterol üzerindeki etkisi nedeniyle HPI'nin de 1'in üstünde olması tavsiye edilmiştir (Fernandes, 2014; Zula ve Desta, 2021 Örneklerimizdeki AI, %0.43; TI, %0.38; h/H, %2.69 şeklinde hesaplanmıştır. Atatürk barajında AI, %0.64, TI, %0.41 (Yakar vd., 2023); Keban barajındaki Gökkuşağı alabalıklarında (*Oncorhynchus mykiss*) AI, 0.38; TI, 0.33; h/H, 2.50 ve HPI ise ortalama 2.57 olarak tespit edilmiştir (Bengü, 2024). Çalışmada, besleyici değer indeks BDİ (NVİ) ortalaması 1.97; sağlığı geliştiren indeks (HPI), %3.05 ve arzu edilen yağ asidi miktarı (DFA) ise %72.67 olarak hesaplanmıştır. DFA, yılan balıklarında %74.36 (Łuczyńska vd., 2023); *S.glanis*'te ise %68.80 olarak belirlenmiştir (Đuričić, 2022). BDİ (NVI); %1.23 (Zula ve Desta, 2021); HPI %1.82 olarak kaydedilmiştir (Łuczyńska vd., 2023). *A. grypus*'ta OFA (Hiperkolesterolemik), %22.12 seviyesinde olduğu gözlenmiştir. Balıklarda n-3/n-6 gibi büyüme performansını gösteren ARA/EPA (Araşidonik asit/EPA), %1.05 olarak hesaplanmıştır. *A. grypus*'ta PI %13.53, Avrupa kedi balığında (*S.glanis*) ise %6.9 olarak tespit edilmiştir (Simeanu vd., 2022). Örneklerimizdeki et-yağ arasındaki ilişkiyi gösteren FLQ %12.13; Atlantik somon'unda %7.19 (*Salmo salar*) (Erdem ve Dinçer, 2023); Levrekte %4.53 ve Çipurada ise %3.06 (Pleadin vd., 2017) olarak tespit edilmiştir. Bu verilerden *A. grypus*'ların yağlı olduğu sonucu ortaya çıkmıştır.

4. Sonuç

Şabut balığında *(A. grypus)* yaptığımız çalışmada ARA/EPA, FLQ, HPI, DFA ve BDİ (NVİ) gibi beslenme indeks değerleri hesaplanmıştır. Son zamanlarda yapılmış bazı çalışmalarda, sağlığa katkılarından dolayı besleyicilik kalite indeksi olan ARA/EPA'nın, n-3/n-6 kadar yararlı olduğu belirtilmiştir (Magalhaes vd., 2020; Özer vd., 2022). *A, grypus* ile ilgili bu çalışmadaki FLQ, BDİ, FI, TI, ARA ve HPİ gibi bazı lipit sağlık indekslerinin ileriki çalışmalar için bir kaynak oluşturacağını düşünmekteyiz. Sonuç olarak *A. grypus*'lardaki PUFA/SFA değeri, tavsiye edilen 0.45'in üzerinde (%0.89); AI ve TI değerleri ise 1'in altında olduğu saptanmıştır. n3/n6 ortalaması 1.33; h/H değeri %2.25 (2'nin üzerinde) ve büyüme performansı ARA/EPA değeri de 1.05 olarak hesaplanmıştır. Şabut balığının (*A. grypus*) besin kalitesi ve sağlık indeksleri, önerilen sınırlarda olduğu tespit edilmiştir. Sağlık açısından Şabut balığının (*A. grypus*), önerilen sanojenik indeks ve besin kalitesindeki pozitif sonuçlar nedeniyle düzenli olarak tüketilebileceği belirlenmiştir. Sonuç olarak, *Arabibarbus grypus*'ların hem sağlığa katkısı hem de beslenmeye yönelik yararları nedeniyle tüketicilere önerilebileceği tespit edilmiştir.

5. Teşekkür

Yazarlar, değerlendirme sürecinde yapıcı öneriler sunan editör ve hakemlere teşekkür eder.

6. Etik Standartlara Uyum

a) Yazarların katkıları

1. R.B, A.Y.Y ve M.Y.D.: Çalışmayı tasarladı ve verileri yorumladı.
2. R.B, A.Y.Y ve M.Y.D: Laboratuar çalışmasını gerçekleştirdi.
3. R.B, A.Y.Y ve M.Y.D: Laboratuar çalışmasını gerçekleştirdi ve makaleyi hazırladı.

b) Çıkar çatışması

Yazarlar çıkar çatışması olmadığını beyan ettiler.

c) Hayvanların Refahına İlişkin Beyan

Bu tür bir çalışma için resmi onay gerekli değildir.

d) İnsan Hakları Beyanı

Bu çalışma insan katılımcıları kapsamamaktadır.

e) Yapay zekâ kullanmama beyanı

Yazarlar, bu makalenin yazımında, görsellerin, grafiklerin, tabloların ya da bunlara karşılık gelen başlıkların oluşturulmasında herhangi bir tür üretken yapay zekâ kullanmadıklarını beyan ederler.

7. Kaynakça

Ahmed, I., Jan, K., Fatma, S., & Dawood, M.A. (2022). Muscle proximate composition of various food fish species and their nutritional significance: A review. *Journal of Animal Physiology and Animal Nutrition*, 106(3): 690-719. https://doi.org/10.1111/jpn.13711

Ainiwaer, T., Babaoğlu, A.S., Unal, K., & Karakaya, M. (2025). A comprehensive study of the fatty acid composition, thermal and some physicochemical properties of abdominal and subcutaneous fats of Linda, Mast and Turkish geese. *Tropical Animal Health and Production*, 57(1): 1. https://doi.org/10.1007/s11250-024-04248-9

Aydın, E., Özdemir, N.Ş., & Sökmen, T.Ö. (2024). Çaltıcak (Taşkısığı) Gölü (Sakarya, Türkiye) Balık Türlerinin Boy-ağırlık İlişkileri ve Kondisyon Faktörleri. Acta Aquatica Turcica, 20(4): 298-311. https://doi.org/10.22392/actaquatr.1451579

Aysondu, H., Özyürek, S., & Türkyılmaz, D. (2022). Comparative Study between Ewe and Goats Milk Fatty Acid Profile and Some Healthy Index in the First 30 Days of Lactation. Van Veterinary Journal, 33(1): 31-35. https://doi.org/10.36483/vanvetj.1068512

Başusta, A., & Girgin, H. (2023). Murat Nehri'nde yaşayan *Acanthobrama marmid* (Heckel, 1843)'in balık boyu-otolit boyutları arasındaki ilişki. Ecological Life Sciences, 18 (4): 135-145. http://dx.doi.org/10.12739/NWSA.2023.18.4.5A0198

Bayar, İ., İnci, A., Aypak, S.Ü., & Bildik, A. (2021). Büyük Menderes Nehri'nde (Aydın) Yaşayan İki Tatlı Su Balığı Türünün Kas Dokularındaki Total Yağ Asidi Kompozisyonunun Araştırılması. Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi, 24(2): 260-266. https://doi.org/10.18016/ksutarimdoga.vi.723089

Bektas, Y., Aksu, I., Kalaycı, G., & Bayçelebi, E. (2020). Low genetic diversity in Turkish populations of wels catfish *Silurus glanis* L., 1758 (Siluridae, Pisces) revealed by mitochondrial control region sequences. Turkish Journal of Fisheries and Aquatic Sciences, 20(10): 767-776. https://doi.org/10.4194/1303-2712-v20_10_06

Bengü, A. Ş. (2024). Keban baraj gölünden yakalanan gökkuşağı alabalığı (*Oncorhynchus mykiss*)' nın bazı besin içeriğinin değerlendirilmesi. *Türk Tarım ve Doğa Bilimleri Dergisi*, 11(2): 321-329. https://doi.org/10.30910/turkjans.1390700

Bozkurt, R., Yüksel, A.Y., Dörtbudak, M.Y., & Parmaksız, A. (2024). Determination of fatty acid composition of *Silurus triostegus* Heckel, 1843 and *Arabibarbus grypus* Heckel, 1843 species living in Ilısu Dam Lake (Batman/TÜRKİYE). International Journal of Life Sciences and Biotechnology, 7(2): 74-79.

Cengiz, B., Şeker, E., & Özcan, E.İ. (2024). Karakaya Baraj Gölü'nde Yaşayan *Arabibarbus grypus* (Heckel, 1843)(Şabut) Populasyonunun Bazı Büyüme Özelliklerinin Belirlenmesi. *Journal of Anatolian Environmental and Animal Sciences*, 8(3):306-312. https://doi.org/10.35229/jaes.1298332

Chen, S., Bobe, G., Zimmerman, S., Hammond, E.G., Luhman, C.M., Boylston, T.D., ... & Beitz, D.C. (2004). Physical and sensory properties of dairy products from cows with various milk fatty acid compositions. *Journal of Agricultural and Food Chemistry*, 52(11): 3422-3428. https://doi.org/10.1021/jf035193z

Chen, Y., Qiao, Y., Xiao, Y.U., Chen, H., Zhao, L., Huang, M., & Zhou, G. (2016). Differences in physicochemical and nutritional properties of breast and thigh meat from crossbred chickens, commercial broilers, and spent hens. *Asian-Australasian journal of animal sciences*, 29(6): 855. http://dx.doi.org/10.5713/ajas.15.0840

Cholidis, P., Kranas, D., Chira, A., Galouni, E. A., Adamantidi, T., Anastasiadou, C., & Tsoupras, A. (2024). Shrimp Lipid Bioactives with Anti-Inflammatory, Antithrombotic, and Antioxidant Health-Promoting Properties for Cardio-Protection. Marine Drugs, 22(12): 554. https://doi.org/10.3390/md22120554

Ciobanu, M.M., Boisteanu, P.C., Simeanu, D., Postolache, A.N., Lazar, R., & Vintu, C.R. (2019). Study on the profile of fatty acids of broiler chicken raised and slaughtered in industrial system. Rev. Chim, 70(11):4089-4094.

Çaklı, Ş., Erol, N. D., Şen Yılmaz, E.B., Baldemir, P., & Çaklı, A. (2023). Determination of lipid quality and mercury levels of sardine and rainbow trout cooked with different methods. *Ege Journal of Fisheries & Aquatic Sciences (EgeJFAS)/Su Ürünleri Dergisi*, 40(3): 182-188. https://doi.org/10.12714/egejfas.40.3.04

Dernekbaşı, S., Akyüz, A.P., & Karayücel, İ. (2021). Effects of total replacement of dietary fish oil by vegetable oils on growth performance, nutritional quality and fatty acid profiles of rainbow trout *(Oncorhynchus mykiss*) at optimum-and high temperature conditions. *Ege Journal of Fisheries and Aquatic Sciences*, 38(2):237-246. https://doi.org/10.12714/egejfas.38.2.14

Dinç, H. & Dörtbudak, M.Y. (2020). Investigation of toxic effects of heavy metal level in atatürk dam. Experimental and applied medical science. 1(1): 23-28. https://doi.org/10.31594/commagene.1079557

Doğu, Z., Aral, F., & Şahinöz, E. (2014). The determınatıon of some spermatologıcal and hematologıcal parameters of shabbout (*Barbus grypus*, h; 1843) ın Atatürk dam lake, Şanlıurfa. Journal of FisheriesSciences. com, 8(4): 265-277. https://doi.org/10.3153/jfscom.201432

Đuričić, I., Gojković, T., Antonijević, B., & Šobajić, S. (2022). Lipid profile and health benefit of commonly consumed fresh water and sea water fish species in the population of Serbia. *Vojnosanitetski pregled*, 79(1): 8-16. https://doi.org/10.2298/VSP200212054D

Egessa, R., Szűcs, A., Ardó, L., Biró, J., Lengyel-Kónya, É., Banjac, V., ... & Sándor, Z.J. (2024). Dietary inclusion of insect oil: Impact on growth, nutrient utilisation, lipid metabolism, antioxidant and immune-related responses in European catfish (*Silurus glanis L*). *Aquaculture*, 592: 741213. https://doi.org/10.1016/j.aquaculture.2024.741213

Erdem, Ö.A., & Dinçer, M.T. (2023). Effects of different cooking methods on the proximate and fatty acid composition of Atlantic salmon (*Salmo salar*). *Ege Journal of Fisheries and Aquatic Sciences*, 40(4): 251-258. https://doi.org/10.12714/egejfas.40.4.03

Fernandes, C.E., da Silva Vasconcelos, M.A., de Almeida Ribeiro, M., Sarubbo, L.A., Andrade, S. A.C., & de Melo Filho, A.B. (2014). Nutritional and lipid profiles in marine fish species from Brazil. *Food chemistry*, 160: 67-71. https://doi.org/10.1016/j.foodchem.2014.03.055

Folch, J., Lees, M., G.H. Sloane-Stanley (1957). A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biological Chemistry*, 226(1): 497-509. https://doi.org/10.1016/S0021-9258(18)64849-5

Gokce, M.A., Tasbozan, O., Tabakoglu, S.S., Celik, M., Ozcan, F., & Basusta, A. (2011). Proximate composition and fatty acid profile of shabbout (*Barbus grypus* Heckel, 1843) caught from the Ataturk Dam Lake, Turkey. Journal of Food, Agriculture & Environment, 9(2): 148-151. https://doi.org/10.1234/4.2011.2077

Güllü, K., İnanan, B.E., Öğretmen, F., Gölbaşı, S., & Yılmaz, F. (2015). Effects of seminal plasma properties on percentage and duration of shabut (*Barbus grypus* Heckel, 1843) Sperm Motility. Israeli Journal of Aquaculture, 67:1-9. https://doi.org/10.46989/001c.20700

Haq, M., Ali, M.S., Park, J.S., Kim, J. W., Zhang, W., & Chun, B.S. (2025). Atlantic salmon (*Salmo salar*) waste as a unique source of biofunctional protein hydrolysates: Emerging productions, promising applications, and challenges mitigation. *Food Chemistry*, 462: 141017. https://doi.org/10.1016/j.foodchem.2024.141017

Henderson, R.J., & Tocher, D.R. (1987). The lipid composition and biochemistry of freshwater fish. Progress in lipid research, 26(4): 281-347. http://dx.doi.org/10.1016/0163-7827(87)90002-6

Jung, S.J., Baek, H.I., Park, E.O., Ha, K.C., Park, D.S., Chae, S.W., & Lee, S.O. (2025). Immunomodulatory effects of supercritical CO 2 extracted oils from *Portulaca oleracea* and *Perilla frutescens* (PPCE) in healthy individuals: a randomized double-blind clinical trial. *Food & Function*. 16: 1708-1719. https://doi.org/10.1039/D4FO03361B

Kaçar, S., & Başhan, M. (2022). *Silurus triostegus'* un Gonat Dokusu Yağ Asidi İçeriğinin Mevsimsel Değişimi. *Acta Aquatica Turcica*, 18(1): 24-37. https://doi.org/10.22392/actaquatr.934517

Kandemir, Ş. & Polat, N. (2007). Seasonal Variation of Total Lipid and Total Fatty Acid in Muscle and Liver of Rainbow Trout (*Oncorhynchus mykiss* W, 1792) Reared in Derbent Dam Lake. *Turkish Journal of Fisheries and Aquatic Sciences*, 7(1):27-31.

Karadede, H., Oymak, S. A., & Ünlü, E. (2004). Heavy metals in mullet, *Liza abu*, and catfish, *Silurus triostegus*, from the Atatürk Dam Lake (Euphrates), Turkey. *Environment International*, 30(2): 183-188. https://doi.org/10.1016/S0160-4120(03)00169-7

Kutlu, B., Sesli, A., Tepe, R., & Mutlu, E. (2015). Assessment of physico-chemical water quality of birecik dam, Şanlıurfa, west east region, turkey. *Turkish Journal of Agriculture-Food Science and Technology*, 3(7): 623-628. https://doi.org/10.24925/turjaf.v3i7.623-628.423

Liang, J., Zhou, Q., Wang, C., Gao, X., Yuan, Y., Zhu, Z., ... & Yang, S. (2024). Ecosystem-level response to complex disturbances of an interconnected river–lake system based on Ecopath model over the last 30 years. *Hydrobiologia*, 851: 4585–4600. https://doi.org/10.1007/s10750-024-05611-5

Łuczyńska, J., Nowosad, J., Łuczyński, M. J., & Kucharczyk, D. (2023). Evaluation of Chemical Elements, Lipid Profiles, Nutritional Indices and Health Risk Assessment of European Eel (*Anguilla anguilla* L.). *International Journal of Environmental Research and Public Health*, 20(3): 2257. https://doi.org/10.3390/ijerph20032257

Magalhães, R., Guerreiro, I., Coutinho, F., Moutinho, S., Sousa, S., Delerue-Matos, C., ... & Oliva-Teles, A. (2020). Effect of dietary ARA/EPA/DHA ratios on growth performance and intermediary metabolism of gilthead sea bream (*Sparus aurata*) juveniles. *Aquaculture*, 516: 734644. https://doi.org/10.1016/j.aquaculture.2019.734644

Magdici, E., Nistor, C.E., Pagu, I.B., Hoha, G.V., Avarvarei, B.V., & Pasarin, B. (2014). Research regarding the influence of slaughtering age on quantitative meat production at European catfish (*Silurus glanis*). *Journal of Biotechnology*, (185): 576. https://doi.org/10.1016/j.jbiotec.2014.07.258

Marin, S., Castillo, S., Sanchez, R., Collipal, R., Madrid, J., & Farias, A. 2024. Long-term substitution of fish oil with alternative sources in atlantic salmon (*Salmo salar*): performance, health, and consumer appeal. *Aquaculture*, 1-54. http://dx.doi.org/10.2139/ssrn.4692001

Mgbechidinma, C.L., Zheng, G., Baguya, E.B., Zhou, H., Okon, S.U., & Zhang, C. (2023). Fatty acid composition and nutritional analysis of waste crude fish oil obtained by optimized milder extraction methods. *Environmental Engineering Research*, 28(2): 220034. https://doi.org/10.4491/eer.2022.034

Negara, B.F.S.P., Tirtawijaya, G., Cho, W.H., Harwanto, D., Sohn, J.H., Kim, J.S., & Choi, J.S. (2021). Effects of frying processes on the nutritional and sensory characteristics of different mackerel products. *Processes*, 9(9): 1645. https://doi.org/10.3390/pr9091645

Nistor, C.E., Pagu, I.B., Magdici, E., & Păsărin, B. (2014). Study of some morphological characteristics *Oncorhynchus mykiss* breed farmed in salmonid exploatations from Moldova. *Scientific Papers*: Animal Science and Biotechnologies, 47 (1): 22-228.

Ozcan, E.İ. (2020). Murat Nehri (Palu-Elaziğ)'nde Yaşayan *Capoeta trutta* (Heckel, 1843) Türünün Bazı Meristik ve Morfometrik Özellikleri. *Ecological Life Sciences*, 15(4): 155-162. http://dx.doi.org/10.12739/NWSA.2020.15.4.5A0142

Özcan, G., Altun, A., Dörtbudak, M.Y., & Özbek, B.F. (2024). Length-weıght relatıonshıp of *Clarıas garıepınus* ın orontes rıver and gölbaşı lake, Türkiye. *Ecological Life Sciences*, 19(3):115-120. http://dx.doi.org/10.12739/NWSA.2024.19.3.5A0216

Özçiçek, E., Kocabaş, F.K., Kocabaş, M., Özmen, G.K. & Yılmaz, Ö. (2024). Alburnoides velioglui (Turan vd., 2014)'nin Yağ Asidi Profili: Pülümür Çayı (Tunceli) Örneği. *Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergis*i, 10 (3): 154-161. http://dx.doi.org/10.58626/menba.1542856

Özer, Ö., Karakaya, S., & El, S.N. (2022). Gıdaların besleyicilik özelliklerini değerlendiren indeksler. *Gıda*, 47(1): 78-90.). https://doi.org/10.15237/gida.GD21119

Parlak, A.E., Çalta, M., Düşükcan, M., Eroglu, M., & Yılmaz, Ö. (2015). The Determination of fat-soluble vitamins, cholesterol content and the fatty acid compositions of shabut (*Arabibarbus grypus*, Heckel 1843) from Keban dam lake, Elazig, Turkey. *Journal of Fisheries Sciences. com*, 9(3): 24-30.

Parmaksız, A., 2016. Phylogenetıc analysıs of some carp specıes lıvıng ın tıgrıs rıver based on mtdna coı gene sequences. *In International Engineering*, Science and Education Conference (INESEC) Science Proceeding Book, p:47. https://doi.org/10.17693/yunusae.v17i26557.284131

Parmaksız, A & Şeker, Ö., (2018). Genetic diversity of the endemic species shabbout (*Arabibarbus grypus* (Heckel, 1843)) based on partial cytochrome b sequences of mitochondrial DNA. *Aquatic Research*, 1(3):103-109. https://doi.org/10.3153/AR18011

Parmaksız, A., (2023). Mitochondrial DNA sequence analysis of *Arabibarbus grypus* (Heckel, 1843) living in Great Zab (Erbil, Iraq). *Aquatic Research*, 6(1):19-25. https://doi.org/10.3153/AR23003

Păsărin, B., Hoha, G.V., Simeanu, C., & Nistor, C.E. (2023). The influence of thermal frying treatments on the nutritional and health properties of fish meat. *Animal & Food Sciences Journal Iasi Animal & Food Sciences Journal Iasi*, p: 57-63. https://www.uaiasi.ro/firaa/Pdf/Pdf_Vol_79/B_Pasarin.pdf

Pleadin, J., Lesic, T., Kresic, G., Baric, R., Bogdanovic, T., Oraic, D., ... & Zrncic, S. (2017). Nutritional quality of different fish species farmed in the Adriatic Sea. *Italian Journal of Food Science*, 29(3):537-549. https://doi.org/10.14674/IJFS-706

Senso, L., Suárez, M.D., Ruiz-Cara, T., & Garcia-Gallego, M. (2007). On the possible effects of harvesting season and chilled storage on the fatty acid profile of the fillet of farmed gilthead sea bream (*Sparus aurata*). *Food Chemistry*, 101: 298-307. https://doi.org/10.1016/j.foodchem.2006.01.036

Simeanu, C., Măgdici, E., Păsărin, B., Avarvarei, B.V., & Simeanu, D. (2022). Quantitative and qualitative assessment of european catfish (*Silurus glanis*) fesh. *Agriculture*, 12(12): 2144. Https://doi.org/10.3390/agriculture12122144

Srıvastava, S. (2025). Functıonal foods and spıces ın the management of metabolıc syndrome. Nutraceuticals in Obesity Management and Control. editör: Raj K. Keservani, Alka Lohani *Nutraceuticals in Obesity Management and Control, 3*: 462 https://doi.org/10.1201/9781003557883

Taşbozan O, & Gökçe M.A. (2017). Fatty acids in fish. Fatty acids. InTech, 1:143-159. Available from: http://dx.doi.org/10.5772/68048

TS EN ISO 12966-2. (2017). Hayvansal ve bitkisel katı ve sıvı yağlar- Yağ asitleri metil esterlerinin gaz kromotografisi - Bölüm 2: Yağ asitleri metil esterlerinin hazırlanması. TSE publications, Ankara, Turkey.

Uiuiu, P., Cocan, D.I., Lațiu, C., Păpuc, T., Popescu, F., Constantinescu, R., ... & Mireșan, V. (2017). The effect of saline solution used as an activating factor of the semen in brown trout, *Salmo trutta fario* (Linnaeus 1758). *Bulletin UASVM Animal Science and Biotechnologies* 74(2): 169-176. https://doi.org/10.15835/buasvmcn-asb:0028

Ulbricht, T.L.V., & Southgate, D.A.T., (1991). Coronary heart disease: seven dietary factors. *The lancet*, 338(8773): 985-992. https://doi.org/10.1016/0140-6736(91)91846-M

Yakar, Y., Parmaksız, A., Dörtbudak, Y., & Doğan, N. (2023). Investigation of fatty acid profiles in some economically important fish species living in Atatürk Dam Lake, Adıyaman, Türkiye. *Aquatic Research*, 6(1): 11-18. https://doi.org/10.3153/AR23002

Zula, A.T., & Desta, D.T. (2021). Fatty acid-related health lipid ındex of raw and fried Nile tilapia (*Oreochromis niloticus*) Fish Muscle. *Journal of Food Quality*, 2021(1): 6676528. https://doi.org/10.1155/2021/6676528

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

Condition index, meat yield and reproductive cycle of smooth donax, Donax variegatus (Donacidae, Gmelin 1791) in the Eastern Mediterranean

Ali Kırtık[1*]

Abstract: Donax variegatus (Gmelin, 1791) is a small tiny marine bivalve mollusc which is naturally spreaded out in the sandy shores of the Aegean Sea. Although it has recently being used in biomarker studies, there is lack of knowledge on the reproductive cycle of this species. The goal of this study was to evaluate meat yield, condition index, gonad index, gametogenic cycle of Donax variegatus. Donax variegatus specimens were collected monthly between March 2016 and February 2017from the sandy shore of İzmir coast which is located in the Aegean Sea in Eastern Mediterranean. Flesh and gonad tissues were dissected to evaluate condition index, meat yield and histological gonad analysis. Meat yield peaked in April (22.10%) and remained high throughout winter. The condition index rate was the highest in December (20.40%) and April (22.74%) and lowest in October (4.30%). It was observed that gametogenetic activity is synchronized throughout the year for both female and male individuals and spawning has peaked while the water temperature was ranging between 24,1 °C (May) and 28,3 °C (September). It was determined that abiotic factors such as water temperature and nutrient amount, affects gametogenetic activity and morphological indexes ($p<0.05$).

Keywords: smooth donax, Donax variegatus, gametogenic cycle, condition index, bivalve, Mediterranean

Küçük şırlan'ın (Donax variegatus, Donacidae, Gmelin 1791) doğu Akdenizde kondisyon indeksi, et verimi ve üreme döngüsü

Özet: Donax variegatus (Gmelin, 1791) Ege ve Akdeniz'de kumlu kıyılarda doğal olarak yayılım gösteren küçük bir çift kabuklu yumuşakçadır. Son zamanlarda biyobelirteç çalışmalarında kullanılmasına rağmen, literatürde bu türün üreme döngüsü hakkında bilgi eksikliği bulunmaktadır. Bu çalışmanın amacı Donax variegatus'un et verimi, kondisyon indeksi, gonad indeksi ve gametojenik döngüsününün belirlenmesidir. Donax variegatus örnekleri Mart 2016-Şubat 2017 tarihleri arasında Ege Denizi'nde yer alan İzmir ili sahilinin kumlu kıyılarından aylık olarak toplanmıştır. Et ve gonad dokuları kondisyon indeksi, et verimi ve histolojik gonad analizini değerlendirmek için disekte edilmiştir. Et verimi Nisan ayında en yüksek değere ulaşmış (%22,10) ve kış boyunca yüksek seyretmiştir. Kondisyon indeksi oranı Aralık (%20,40) ve Nisan (%22,74) aylarında en yüksek, Ekim (%4,30) ayında ise en düşüktür. Gametogenik aktivitenin hem dişi hem de erkek bireyler için yıl boyunca senkronize olduğu ve yumurtlamanın su sıcaklığı 24,1 °C (Mayıs) ile 28,3 °C (Eylül) arasında değişirken pik yaptığı gözlemlenmiştir. Su sıcaklığı ve besin miktarı gibi abiyotik faktörlerin gametogenik aktivite ve morfolojik indeksleri etkilediği belirlenmiştir ($p<0.05$).

Anahtar Kelimeler: küçük şırlan, Donax variegatus, üreme döngüsü, kondisyon indeksi, çift kabuklu, Akdeniz

Article Info (Research)

1 Ege University, Faculty of Fisheries, Department of Aquaculture, 35100, Bornova, Izmir/Türkiye
***Corresponding Author:** ali.kirtik@ege.edu.tr

Citation: Kırtık, A. (2025), Condition index, meat yield and reproductive cycle of smooth donax, Donax variegatus (Donacidae, Gmelin 1791) in the Eastern Mediterranean, MEMBA Water Sciences Journal, 11, (2) 212-223. https://doi.org/10.58626/memba.1728279

Submission Date: 14 February 2025
Acceptance Date: 16 May 2025
Publishing Date: 28 June 2025

1. Introduction

Donax variegatus is an Atlantic-Mediterranean warm water bivalve species (Neuberger-Cywiak et al. 1990, Fernández-Perez, et al. 2017) distributed along the Mediterranean including Aegean Sea and Marmara Sea coasts of Turkey (Öztürk et al., 2014; Manousis, 2021). Bivalves species of the genus Donax are important aquatic species, especially in the sandy coastal zones of Mediterranean Sea (Neuberger-Cywiak et al. 1990). It lives in sandy and rarely pebbly areas on the coastline between 0 - 2 m in the Mediterranean (La Valle et al. 2007). Thanks to their physiological and behavioral adaptations, they maintain their position especially in the intertidal zone and can avoid drying risks (Neuberger-Cywiak et al., 1990). The shell structure of Donacidae species (Moueza and Cheesel 1976) regarding the length-width relationship is important that they can easily bury themselves in the sand (Trueman and Ansel, 1969).

The meat yield and condition index are the most widely used quantitative methods in culture applications of bivalves is a considerable method because of its simplicity in the monitoring of gametogenetic activities (Okumuş and Stirling, 1998; Yildiz et al., 2006). Patiño et al. (2021) reported that environmental conditions have a substantial effect on the gonad index and meat yield, and these values are lower in less productive waters. In the study conducted by Deval (2009) in Northern Marmara Sea, it was reported that the condition index of D. trunculus increased in February, reached the highest in May, and decreased to the lowest in the August.

In histological studies to determine the reproductive period in bivalves, gonad stages were generally determined as Stage I: immature or post spawned gonads, Stage II: sex microscopically determinable and Stage III: ripe the gonads (Lucas, 1965). The biotic and abiotic factors are considered to effect on the differences in the reproductive periods. Determination of reproductive activity ensures effective and sustainable use of resources with an evaluable framework for fisheries and aquaculture management. The knowledge about biology and ecology of especially Donax trunculus and some mud shell species are existing (Moueza 1971, Moueza and Frenkiel-Renault 1973, Moueza and Chessel 1976, Deval 2009, De la Huz et al. 2002, Gaspar et al. 2002b; Yılmazer 2005, Aydın et al. 2020), whereas there is no information on reproductive biology for D. variegatus. In studies with the reproductive periods of Donax species, Tiriado and Salas (1999) reported that D. venustus and D. semistriatus spawning occurs almost throughout the year. Zeichen et al. (2002) reported that D. trunculus spawns in summer. Many economic bivalve species such as mussels, oysters, pearl oyster and carpet shells are distributed in Turkey coasts, and studies are carried out on these species in Turkey as well (Yıldız et al. 2013, Acarlı et al. 2018, Yiğitkurt et al. 2020, Yiğitkurt 2021). Apart from the commercial bivalve species, the importance of scientific studies on these non-commercial species (for now) is increasingly contributing to the knowledge and economy. In addition, a lot of non- commercial species are captured as bycatch because of overfishing of these bivalve species. The knowledge about the reproductive cycle of a species is a key feature for law-makers to ban or decision make of fishing for conservation of this species. The aim of this study is to eliminate the serious lack of knowledge in reproductive biology of D. variegatus and determine the effects of environmental factors on meat yield, condition index, gonad index, gametogenic cycles.

2. Materials and Methods

Sampling site

Donax variegatus specimens (n=60) was monthly collected from the sandy intertidal coast of Ozbek village (38.20519° N- 26.40556° E) in Izmir between March 2016 and February 2017. They were handpicked from a depth of 15-20 cm with a sieve and immediately transferred to the laboratory in heat-insulated containers.

Environmental conditions

The sea water temperature and salinity were recorded by a multiparameter probe (YSI 6600) at the sampling site monthly. In addition, water sample that was taken from the study site with heat insulated containers transferred to the laboratory to evaluate further environmental parameters such as particulate matter and chlorophyll-a. Total particle matter (TPM), particulate organic matter (POM), particulate inorganic matter (PIM) and chlorophyll-a (µg/l) were determined according to the filtering method of Strickland and Parsons (1972). Water sample was filtered by Whatman CF/C 47mm in diameter glassfiber filters (0.7 µm pore size) and chlorophyll-a was measured by spectrophotometric method. Particulate matter was also measured by filtering method by Whatman GF/C glass fiber filters.

Meat Yield and Condition Index

Biometric measurements of individuals such as shell length (SL) (maximum antero-posterior distance), shell height (SH) (maximum distance from hinge to ventral margin) and shell width (SWi) (maximum distance between outer edges of two valves) were measured using a digital caliper (Mitutuyo CD-15PK). Weight (TW) of individuals were weighed on a precision scales (Sartorius GW3202-O CE 0.001 g). Shells were opened by using a disenfected scalpel, gonad tissues were dissected from the area between foot and stomach, and flesh were seperated from shells. Monthly 30 samples were used to evaluate meat yield and condition index. The flesh of the individuals was frozen at -18°C in the freezer, then dried in a freeze dryer (Chryst Alpha 1-2 LD). Shells were dried in a heating oven (Binder ED 23) at 45°C. Meat yield (MY), condition index (CI) were calculated monthly according to the formulas as follows during the study (Walne, 1976; Okumuş and Stirling 1998, Pekkarinen 1983).

Meat Yield= (wet meat weight (g))/ (total weight (g)) ×100
Condition Index= (dry meat weight (g))/ (dry shell weight (g)) ×100

Gametogenic Cycle and Gonad Index

The year-round state of gonad development of D. variegatus was investigated histologically. Dissected gonad tissues were fixed in Davidson's solution for 48 h (Shaw and Battle 1957). Then tissues were dehydrated with alcohol, and cleared with xylene series, embedded in paraffin (Histowax, Leica), cross-sectioned to a thickness of 5 µm with a microtome (Shandon Finesse 325). Cross-section of samples were dyed with haematoxylin and 0.5% eosin (Howard, 1983). The gametogenic cycle were evaluated as 5 phases which are indifferent, development, ripe, spawning and spent; according to Gaspar et al. (1999) as follows:

In inactive stage, gender cannot be defined because there are no gamete cells and gonad consist of connective tissue (Figure 1A). In development stage, spermatogonia and spermatocytes are seen in the newly formed follicle in male individuals (Figure 1B) and previtellogenic and vitellogenic oocytes are seen in the follicles that begin to form between the connective tissue in females (Figure 1C). In ripe stage, the volume of the follicles reaches its maximum level in both sexes. In male individuals, spermatids and spermatozoa are seen in the follicle (Figure 1D) while vitellogonic and mature oocytes are seen in the follicle in ripe female individuals (Figure 1E). In spent stage, for both sexes, a cavity appears in the center of the follicle. In male individuals, spermatozoa in the follicle are decreased, similarly, in females; mature oocytes in the follicle are decreased (Figure 1F, 1G). The follicles are almost empty and there are few spermatozoa, which we call residual spermatozoa, within the follicle (Figure 1H). In the female gonads, a residual oocyte is also seen in the follicle lumen (Figure 1I).

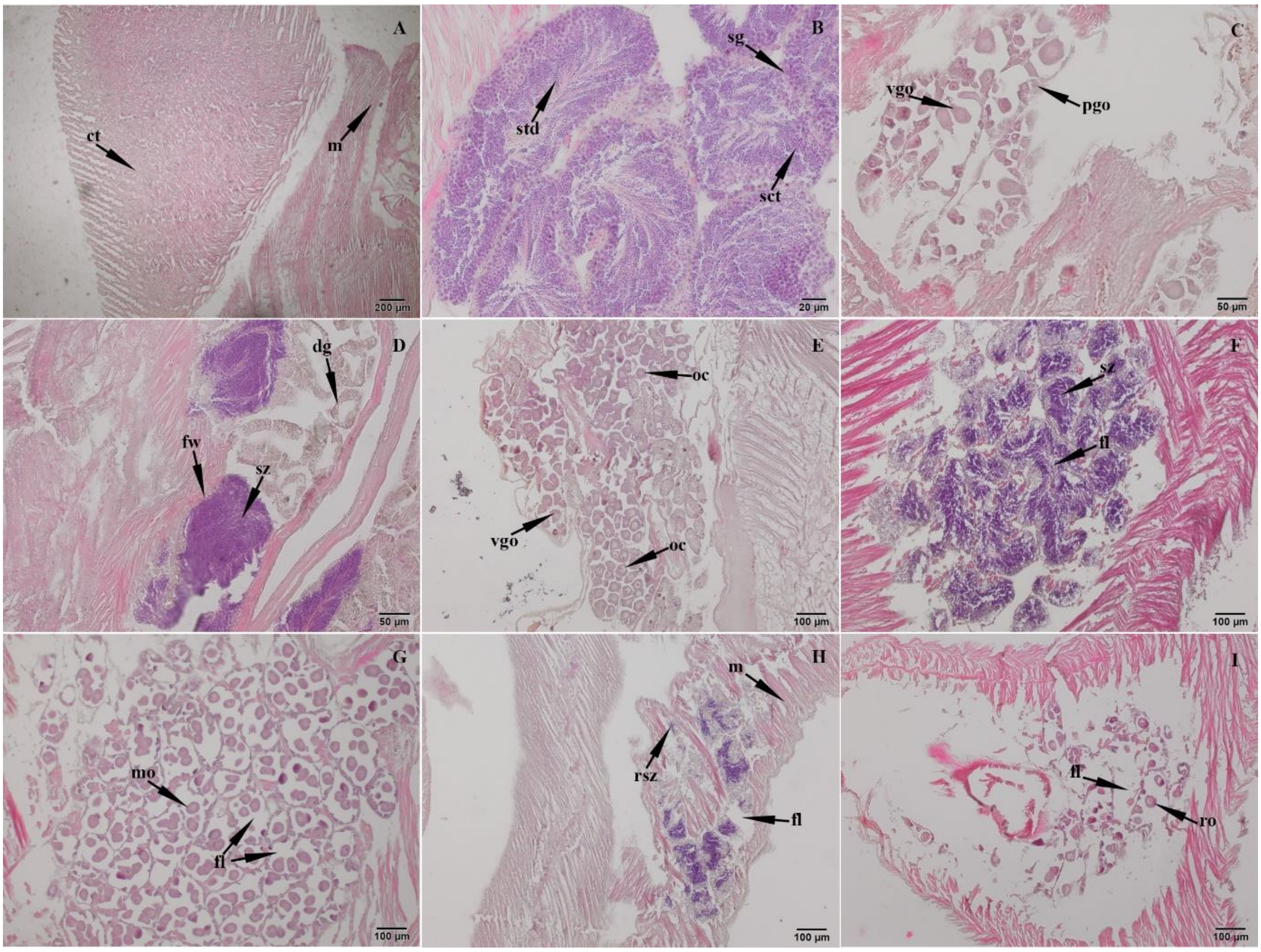


Figure 1. Gonadal stages of Donax variegatus (A – Stage 0: Inactive (ct:connective tissue, m:muscel); B – Stage 1: Development in male (Std: Spermatid, Sg: Spermatogonia, Sct: Spermatocyte; C – Stage 1: Development in female(Pgo: Previtellogenic oocyte, Vgo: Vitellogenic oocyte); D – Stage 2: Ripe male (Sz: Spermatozoa, Fw: Follicular wall, dg:digestive gland), E – Stage 2: Ripe female (oc: Mature oocyte, Vgo: Vitellogenic oocyte); F – Stage 3: Spawning in male (Sz: Spermatozoa, Fl: Follicul lumen), G – Stage 3: Spawning in female (Mo: Mature oocyte, Fl: Follicular lumen); H – Stage 4: Spent in males (Fl: Follicular lumen, sz: Residual spermatozoa, m: muscel); I – Stage 4: Spent in females (Fw: Follicular lumen, Ro: Residual oogonia)

Gonad index (GI) values were calculated monthly according to the formula (Soria et al. 2002) as follows:

Gonad Index=[(Indifferent individual+Spent individuals)x 1 + (Development individuals)x 2 + (Ripe individuals+Spawning individuals)x 3)]/(Total Individuals (n))

Statistical analysis

While evaluating the results of meat yield and condition index, the ANOVA test was applied when the variance was homogeneous, and the Kruskall-Wallis test applied when variance was not homogeneous. Corelation between environmental parameters and MY and CI was analised by Pearson correlation analysis. Pearson correlation analysis was performed to reveal the relationship between meat yield, and condition index values. Confidence interval and significance was choosen 95% and $p<0.05$ respectively during the analysis. Spearman’s correlation test was used to determine the relationship between environmental parameters and gonad development.

3. Results

Temperature increased beggining from March and April, reached the highest in summer months, as well as peaked in September (28.3°C) and mean annual temperature was calculated as 21.86±5.49 at the study site. Chlorophyll-a values increased at the beginning of the study parallel with the rising temperature, annual chlorophyll-a was calculated as 1,76±1,73. The particulate organic matter at the study site was reached it's highest value in October (TPM: 22.87 mg/l; PIM: 15.47 mg/l; POM: 7.40 mg/l) and November, and then decreased (Figure 2).

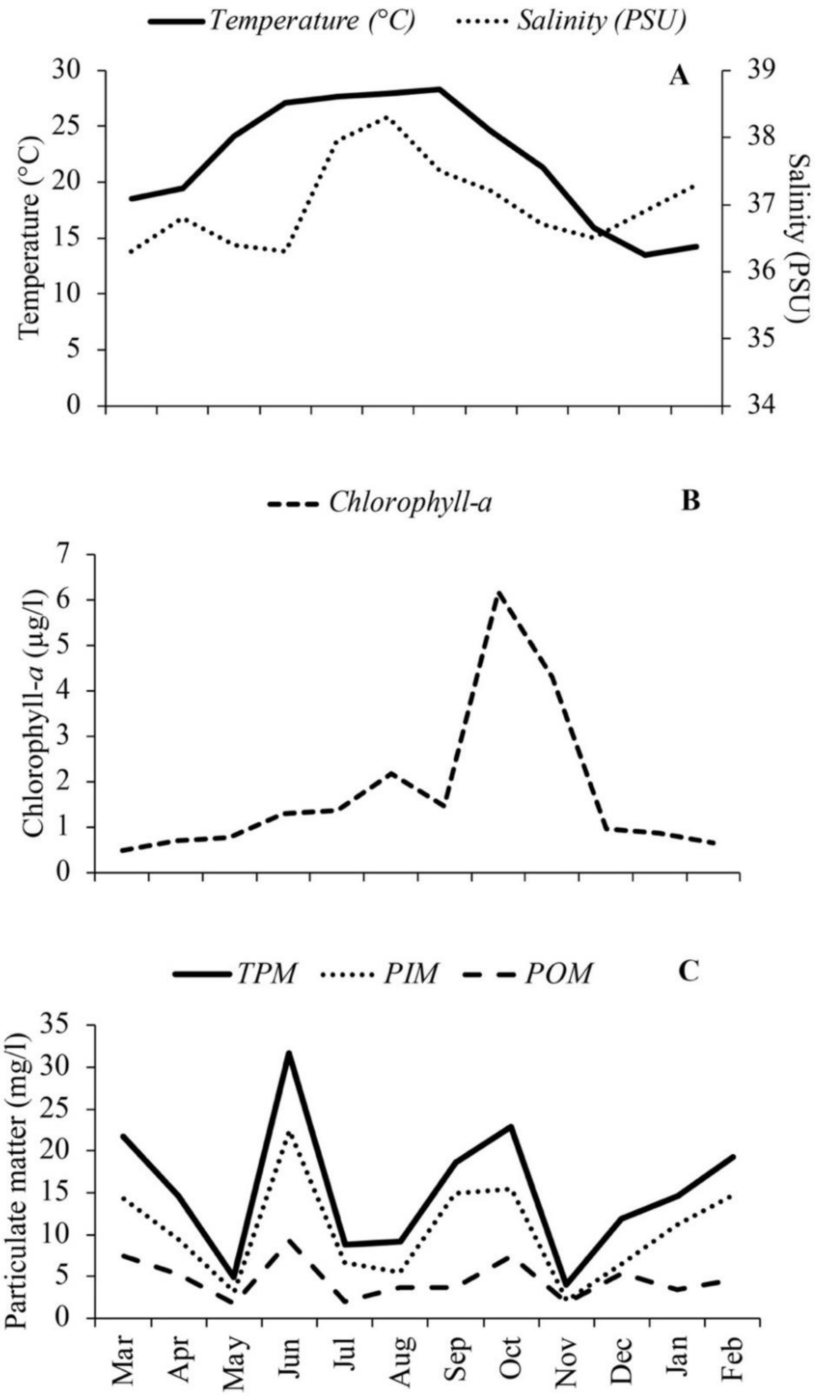


Figure 2. Changes in environmental parameters during the study (A: temperature and salinity, B: Chlorophyll-a, C: TPM, PIM and POM).

The correlation between temperature and gonad index values were positive (R2=0.66) and significant at the 0.05 level. A positive correlation was detected between chlorophyll-a and condition index (R2=0.65).

The mean shell length, height, width and weight of smooth donax that was used throughout the study was 17.53±0.24, 11.06±0.19, 6.16±0.12, 1.01±0.04mm respectively (Table 1).

Table 1. Biometric measurements of *Donax variegatus* (SL, SH, SWi, TW)

Months	N	Length (SL) ± sd (mm)	Height (SH) ± sd (mm)	Width (SWi) ± sd (mm)	Weight (TW) ± sd (mm)
Mar (2016)	30	17.80±0.15	11.38±0.14	6.71±0.11	1.16±0.05
Apr	30	17.58±0.15	10.95±0.24	6.36±0.15	1.01±0.06
May	30	18.06±0.13	11.45±0.10	6.76±0.06	1.16±0.03
Jun	30	18.27±0.23	10.28±0.15	5.73±0.17	0.96±0.05
Jul	30	17.80±0.33	9.74±0.18	5.51±0.14	0.91±0.05
Aug	30	17.02±0.10	10.71±0.10	6.24±0.09	0.93±0.02
Sep	30	17.24±0.21	10.88±0.16	6.33±0.14	0.99±0.05
Oct	30	18.00±0.21	11.66±0.18	6.95±0.15	1.26±0.07
Nov	30	17.23±0.31	10.96±0.24	6.45±0.20	1.07±0.09
Dec	30	17.46±0.28	9.56±0.16	5.15±0.12	0.72±0.04
Jan	30	18.65±0.22	10.41±0.13	5.85±0.09	0.96±0.04
Feb (2017)	30	19.24±0.18	10.78±0.13	5.88±0.09	1.09±0.04
Mean		17.53±0.24	11,06±0.19	6.16±0.12	1.01±0.04

*sd (standart deviation)

In the study, meat yield peaked in April (22.21%) and remained at high until February. The condition index peaked in April (11.89%), and the lowest was observed in October (3.23%) (Figure 2). A positive correlation was detected between meat yield and condition index (R2=0.61) (Figure 3).

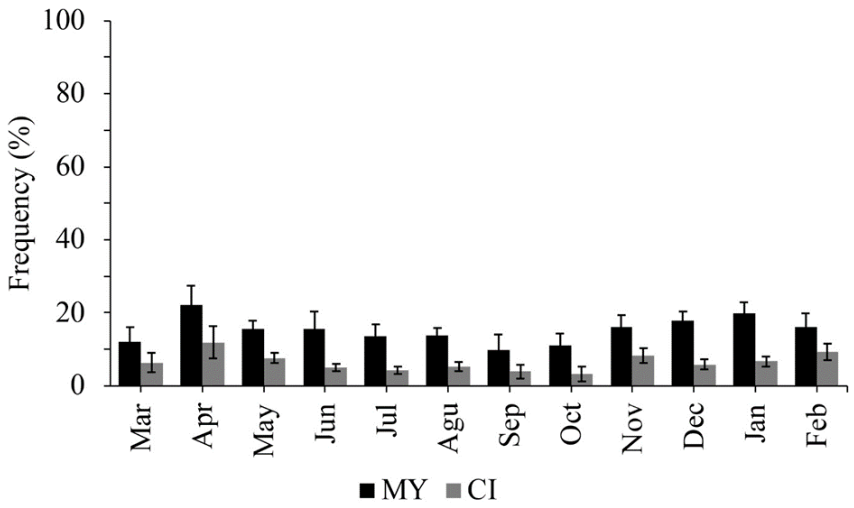


Figure 3. Meat yield (MY) and Condition index (CI) of Donax variegatus

It was observed that male and female individuals showed a synchronized reproductive activity by developing and maturing and then spawning at the same time during the study. While all stages were observed in March, April and May, the development stage was not observed in June and July. An intense reproduction activity was detected in the population between May and September. As of September, the resting, maturity, spawning stages as well as the development stage; have started to be seen again until in June. Although number of spawning individuals decreases and increases between months, it is found that spawning continues throughout the year in the population (Figure 4).

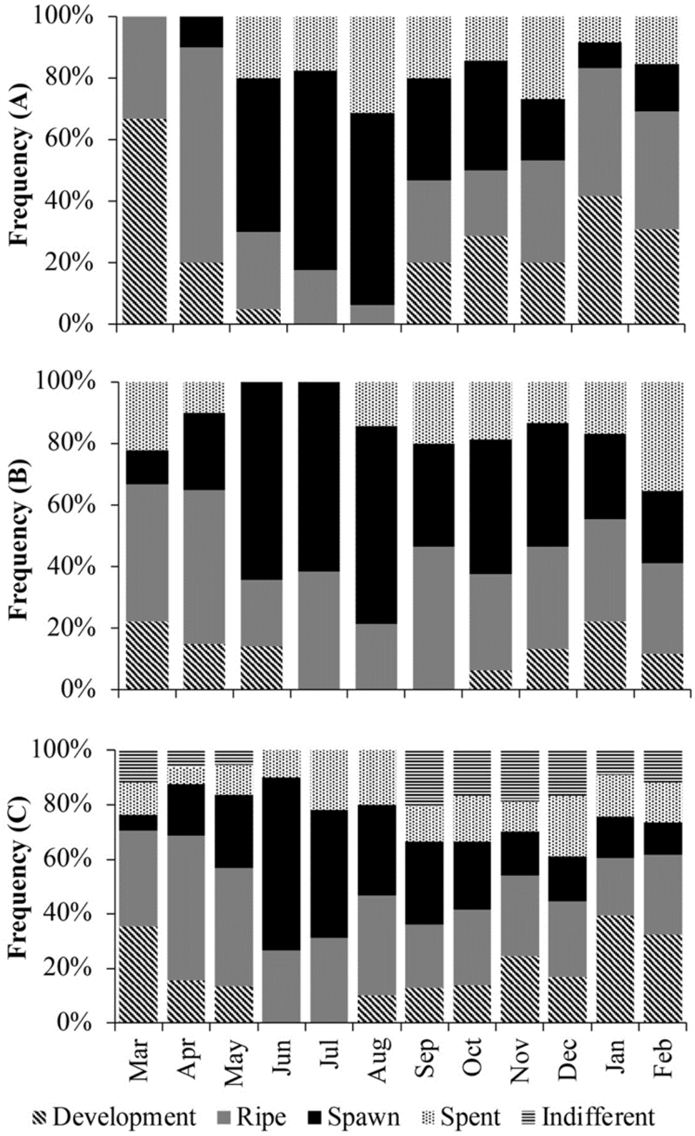


Figure 4. . Annual frequency of gametogenic activity of Donax variegetus (A: female, B:male, C:total reproductive activity).

A peak in GI was observed (2.26%) in June and following months the GI values were decreased and it was at the lowest in March (1.47%) which means the D. variegatus population was very active in terms of reproductive efficiency in June (Figure 5).

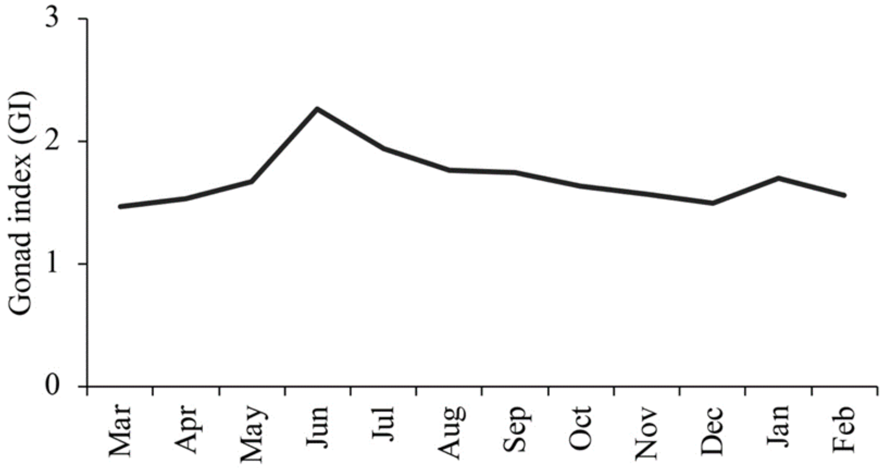


Figure 5.The gonad index of D. variegatus.

4. Discussion

Studies on D. variegatus are generally focuses on population and genetics. Since there is little information about it's biology (Ansell and Lagardere 1980), comparisons have been made with other Donax species is related to gametogenesis. Aydın et al. (2020) reported that Donax species in the Marmara region are larger than those in the Black Sea region. In length studies with Donax orangelus, the length range is 3-44 mm in the North Marmara Sea (Deval 2009), and 5-45 mm in Spain (De la Huz et al. 2002), 8-44 mm and 16-44 mm on the South Coast of Portugal (Gaspar et al. 2002b). Length range of 3.6 mm-26.1 mm was reported during a study conducted with D. incornatus in India (Thippeswamy and Mohan Joseph 1992). The reason for the difference in shell lengths between our study (14.66-19.24 mm.) and other studies suggests that besides species differences, abiotic factors have a profound effect on smooth donax growth such as nutrient and temperature.

The weight of D. trunculus individuals collected from the Southern coasts of Black Sea was determined as 1.2±1.1 g (Aydın et al. 2020) and in another study conducted in the Marmara Sea, it was 3.81±0.12 g (Lök et al. 2011). In this study, lower mean weight (1.01±0.04 g) was measured due to diversity of species and D. variegatus' smaller individuals compared to the other studies that are conducted at the north. It can be concluded that the location might be a key feature for these species in terms of weight.

According to the results of a previous study conducted in different regions of Turkey, D. trunculus condition index values were reported as 53.91% to 94.25% in Marmara Sea (Çolakoğlu and Tokaç 2011). When compared to other studies, lower condition index values was found in this study (4.30%-22.7%) similarly with the weight results. Similarities and differences in condition index values have reported to be related with water temperature and chlorophyll-a changes (Martínez Pita and Moreno 2019). Higher gonadosomatic and condition index is seen in more productive regions which are rich in chlorophyll-a concentrations and it supports the development of gonad tissue (Patino et al. 2021) and causes increase in spawning.

Meat yield varies by region as well as by years. This is because environmental conditions can have a great ecological and physiological effect on the intertidal bivalves. Meat yield decreases as low tide, high water temperature and sudden salinity decrease affect sand digging activity (Macho et al. 2016). The meat yield was reported as 22.68% for D. trunculus during a study conducted in Marmara Sea in 2012 (Lök et al. 2011). Ansell and Lagardere (1980) stated that the meat yield of D. trunculus was minimum between October and December and increases during spring then it reaches the highest level in summer, in the Algerian coast. In the current study, the highest meat yield was determined in April, and an increase was observed in winter. When considered that, bivalve molluscs develop their gonadal tissues within the mantle not a separated organ, so it causes fluctuations on meat yield variations and it can be explained that the peak values of the meat yield may be associated with gonad because gametogenesis has been detected in winter and spring.

Although the reproductive period of D. trunculus varies according to the region, it was reported that gametogenesis generally starts in the winter, spawning occurs in summer, and the resting phase lasts from the end of summer to the end of winter in the Mediterranean (Moueza and Chessel 1976, Ansell and Bodoy 1979, Dowidar and El-Nady 1984, Neuberger-Cywiack et al. 1990, Ramon et al. 1995, Gaspar et al. 1999, Beldi 2007). In a study conducted on D. trunculus in the Aegean Sea (Türkiye) in 2012, similar results were found in the reproduction period and spawning was reported between spring and autumn (May-September) (Lök et al. 2011). It was reported that, gametogenesis of D. semistriatus started in winter and spawning continued in winter and summer, and similar results were observed in D. venustus (Tirado and Salas 1999). In this study, reproductive period was found similar to the previous studies of Donax trunculus while gametogenesis was observed between winter and spring, a peak in spawning was detected in summer. Ziechen et al. (2002) reported a year-round spawning activity with intermittent peaks which is similar to the results of the current study.

There is a strong relationship between gametogenesis and condition index in bivalves (Marquardt et al., 2022). CI increases with the beginning of gametogenesis, while CI remains stable in the inactive phase which is similar with the condition index (Deval 2009). In the current study, the condition index increased during gametogenesis, and then peaked in spring, spawning was observed in summer, as expected according to previous studies (Deval, 2009).

Water temperature and chlorophyll-a are related to condition index because seasonal synchronization is seen in morphological indexes under different environmental conditions (Yıldız et al. 2006, Martinez-Pita and Moreno 2019). Significant positive correlation between environmental parameters with gonad index and condition index reveals that, water temperature affects GI ($R2= 0.66$) and chlorophyll-a affects CI ($R2= 0,65$) in this study.

Overfishing of some economic species leads to potential consideration of other species as economic species in the market. Studies on Donacidae species, which are alternative species, are important in terms of contributing as economic candidate species to aquaculture industry. Knowledge of reproductive biology of a species in culture studies sustains survival and clarifies rearing strategy. Even if there are studies on this species in the Atlantic coasts of France, Spain, and Morocco, it is seen that there is still much more limited research in the Mediterranean.

5. Conclusion

According to the results of this study it can be concluded that the reproductive cycle and condition index of sand burrowing Donax variegatus is highly related to water temperature and chlorophyll-a which is essential in terms of bivalve feeding. The results of the current study can contribute to policy makers with conservation strategy of this species in terms of defining the reproduction period. Additionally, conducting further studies such as larval culture or broodstock welfare practices can contribute to the culture of this species regarding as a candidate commercial bivalve.

6. Compliance with Ethical Standard

a) Author Contributions
Single author.

b) Conflict of Interests
The author declared that they have no conflict of interest.

c) Statement on the Welfare of Animals
Any ethics committee protocol does not required for the species that was used in this study.

d) Statement of Human Rights
This study does not involve human participants.

e) Funding
This study was not supported by any founder.

Aknowledgements

Author would like to thank Aynur Lök, Aysun Küçükdermenci, Selçuk Yiğitkurt and Evrim Kurtay for their support during the fieldwork and analysis at the laboratory.

7. References

Acarlı, S., Lök, A., Acarlı, D., Küçükdermenci, A. (2018). Gamogenetic cycle, condition index and meat yield of the Noah's Ark shell (Arca noae Linnaeus, 1758) from Gerence Bay, Aegean Sea Turkey. Ege J. Fish. Aquat. Sci. 35(2):141-149. https://doi.org/10.12714/egejfas.2018.35.2.06

Ansell, A.D., Bodoy, A. (1979). Comparison in events in seasonal cycle for Donax vittatus and Donax trunculus. In: Naylor, E., Hartnoll, R.G. (Eds.), Cyclic Phenomena in Marine Plants and Animals. 191-198 p. Proceedings of the 13th European Marine Biological Symposium. Pergamon Press, Oxford. https://doi.org/10.1016/B978-0-08-023217-1.50032-1

Ansell, A.D., Lagardère, F. (1980). Observations on the biology of Donax trunculus and D. vittatus at Ile d´Ole´ron (French Atlantic coast). Mar. Biol. 57:287–300. https://doi.org/10.1007/BF00387572

Aydın, M., Tunca, E., Esen Ersoy, N. (2020). Morphometric Aspects and Growth Parameters of the Wedge Clam (Donax trunculus) of the Black Sea, Turkey. J. Anatol. Environ. Animal Sci. 5(1):11-18. https://doi.org/10.35229/jaes.637729

Beldi, H. (2007). Etude de Gambusia affinis (Poisson, Téléostéen) et Donax trunculus (Mollusque, Pélécypode): Ecologie, physiologie et impact de quelques altéragènes. Doctoral thesis. University of Badji Mokhtar (Annaba), Algeria. 90 p.

Çolakoğlu, S., Tokaç, A. (2011). Some population parameters of the wedge clam (Donax trunculus L., 1758) in the west Marmara Sea. Ege J. Fish. Aquat. Sci. 28(2): 65-70

De la Huz, R., Lastra, M., Lopez, J. (2002). The influence of sediment grain size on burrowing, growth and metabolism of Donax trunculus L. (Bivalvia: Donacidae). J. Sea Res. 47: 85-95. https://doi.org/10.1016/S1385-1101(02)00108-9

Deval, M.C. (2009). Growth and reproduction of the wedge clam (Donax trunculus) in the Sea of. Marmara, Turkey. J. Appl. Ichthyol. 25:551–558. https://doi.org/10.1111/j.1439-0426.2009.01258.x

Dowidar, N.M., El Nady, F. E. (1984). Seasonal variations in size, weight and biochemical composition of Donax trunculus L. (Pelecypoda, Mollusca) from Abu Kir Bay and Rosetta regions. Bull. Inst. Ocean. Fishs. 10:67-80

Fernández-Pérez, J., Nantón, A., Ruiz-Ruano, F.J., Camacho, J.P.M., Méndez, J. (2017). First complete female mitochondrial genome in four bivalve species genus Donax and their phylogenetic relationships within the Veneroida order. PLoS ONE. 12(9): e0184464. https://doi.org/10.1371/journal.pone.0184464

Gaspar, M.B., Chicaro, L.M., Vasconcelos, P., Garcia, A., Santos, A.R., et al. (2002b). Depth segregation phenomenon in Donax trunculus (Bivalvia: Donacidae) populations of the Algarve coast (southern Portugal). Sci. Mar. 66:111-121. https://doi.org/10.3989/scimar.2002.66n2111

Gaspar, M.B., Ferreira, R., Monteiro, C.C. (1999). Growth and reproductive cycle of Donax trunculus L., (Mollusca: Bivalvia) off Faro, southern Portugal. Fish. Res. 41: 309-319. https://doi.org/10.1016/S0165-7836(99)00017-X

Gaspar, M.B., Santos, M.N., Vasconcelos, P. (2001). Weight-lenght relationships of 25 bivalve species (Mollusca: Bivalvia) from the Algarve coast (southern Portugal). J. Mar. Biolog. Assoc. U.K. 81:805-807. https://doi.org/10.1017/S0025315401004623

Gaspar, M.B., Santos, M.N., Vasconcelos, P., Monteiro, C.C. (2002a). Shell morphometric relationships of the most common bivalve species (Mollusca: Bivalvia) of the Algarve coast (southern Portugal). Hydrobiologia. 477: 73-80

La Valle, P., Belluscio, A., Nicoletti, L., Paganelli, D., Ardizzone, G.D. (2007). Effects of beach nourishment on Donax trunculus in the Latium coasts (Italy, Central Tyrrhenian Sea). MEDCOAST 07. In: The 8th International Conference on the Mediterranean Coastal Environment, Alexandria, Egypt, November 2007, 753–762 p.

Levinton, J.S., (2001). Marine biology. Function, biodiversity, ecology. Oxford University Press, Oxford. 592 p.

Lök, A., Serdar, S., Küçükdermenci A., Kırtık, A., Yiğitkurt, S., et al. (2011). Sustainable Turkish Shellfish Culture, PIA-BOSPHORUS, TÜBİTAK. Project Number: 107Y223, Izmir, 249 p.

Lucas, A. (1965). Recherches sur la sexualité des Mollusques Bivalves. Bull. Biol. Fr. Belg. 99: 115-247

Macho, G., Woodin, S.A., Wethey, D.S., Vazquez, E. (2016). Impacts of sublethal and lethal high temperatures on clams exploited in European fisheries. J. Shellfish Res. 35: 405–419. https://doi.org/10.2983/035.035.0215

Manousis, T. (2021). The Marine Mollusca of Greece: an up-to-date, systematic catalogue, documented with bibliographic and pictorial references. Xenophora Taxonomy. 34: 26-47.

Martinez-Pita, I., Moreno, O. (2019). Improving bivalve fishery management: the development of a tool to

forecast bivalve reproductive season based on environmental data from satellite remote sensing observations. Fish. Oceanogr. 28:698-707 https://doi.org/10.1111/fog.12452
Marquardt AR, Clark NM, Maietta EG, Park SK, Ruttenberg BI (2022) Reproduction, body condition, age, and growth of a large sandy intertidal bivalve, Tivela stultorum. Aquat Biol 31:19-30. https://doi.org/10.3354/ab00749
Moueza, M., and Chessel, D. (1976). Contribution à l'étude de la biologie de Donax trunculus L. (Mollusque: Lamellibranche) dans l'Algerios: analyse statistique de la dispersion le long d'une plage en Baie de Bou Ismaïl. J. Exp. Mar. Biol. Ecol. 21:211-221. https://doi.org/10.1016/0022-0981(76)90116-7
Moueza, M., Frenkiel-Renault, L. (1973). Contribution a¡ l'etude de la biologie de Donax trunculus L. (Mollusques Lamelli-branches) dans l'algerois: la reproduction. Cah. Biol. Mar. 14(3):261-283
Moueza, M. (1971). Contribution à l'étude de l'écologie et de la biologie de Donax trunculus L. (Mollusque Lamellibranche). PhD Thesis. University of Marseille, 130 p.
Nel, R., McLachlan, A., Winter, D.P.E. (2001). The effect of grain size on the burrowing of two Donax species. J. Exp. Mar. Biol. Ecol. 265:219-238. https://doi.org/10.1016/S0022-0981(01)00335-5
Neuberger-Cywiak, L., Achituv, Y., Mizrahi, L. (1990). The ecology of Donax trunculus Linnaeus and Donax semistriatus Poli from the Mediterranean coast of Israel. J. Exp. Mar. Biol. Ecol. 134:203-220. https://doi.org/10.1016/0022-0981(89)90070-1
Ocana, F.A., Fernandez, A. (2011). Morfometría de la concha de Donax denticulatus y Donax striatus de dos playas de Cuba Oriental. Rev. Mar. Cost. 3: 67-75
Okumuş, I., Stirling, H.P. (1998). Seasonal variations in the meatweight, condition index and biochemical composition of mussels (Mytilus edulis L.) in suspended culture in two Scottish sea lochs. Aquac. 159:249-261. https://doi.org/10.1016/S0044-8486(97)00206-8
Öztürk B., Doğan A., Bitlis-Bakir B., Salman, A. (2014). Marine molluscs of the Turkish coasts: an updated checklist. Turk. J. Zool. 38:832-879 https://doi.org/10.3906/zoo-1405-78
Patino DM., Otero J., Louzán A., Ojea J, Vázquez SN, Álvarez-Salgado XA. (2021). Wedge clam (Donax trunculus Linnaeus, 1758) reproduction: reproductive traits andenvironmental influence in the NW Iberian coast and contrast across Atlantic and Mediterranean waters. Hydrobiologia. 848:1347–1366. https://doi.org/10.1007/s10750-021-04532-x
Pekkarinen, M. (1983). Seasonal changes in condition and biochemical constituents in the soft part of Macoma balthica (Lamellibranchiata) in the Tvarminne brackish water area (Baltic Sea). Ann. Zool. Fenn. 20:311-322.
Ramon, M., Abelló, P., Richardson, C.A. (1995). Population structure and growth of Donax trunculus (Bivalvia: Donacidae) in the western Mediterranean. Mar. Biol. 121: 665-671. https://doi.org/10.1007/BF00349302
Rios-Jara, E., del Carmen Esqueda-González, M., Michel-Morfin, J. E., López-Uriarte, E., Salgado-Barragán, J. (2019). Growth and morphometric relationships of the bean clam Donax punctatostriatus Hanle, 1843 in a sandy beach of southern Sinaloa, Mexico. Lat. Am. J. Aquat. Res. 47(5):764-773. https://doi.org/10.3856/vol47-issue5-fulltext-5
Salas–Casanova C. (1987). The Donacidae of the Bay of Malaga (Spain). Taxonomy. Basteria. 51:33– 50.
Shaw BL and Battle HI (1957). The gross microscopic anatomy of the digestive tract of Crassostrea virginica (Gmelin). Canadian Journal of Zoology 35, 325-346.
Soares, A. G., McLachlan, A., Schlacher, T. (1996). Disturbance effects ofstranded kelp on populations of the sandy beach bivalve Donax serra (Röding). J. Exp. Mar. Biol. Ecol. 205:165-186. https://doi.org/10.1016/S0022-0981(96)02595-6
Sokal, R.R., Rohlf, F.J. (1987). Introduction to biostatistics. 2nd ed. New York: Freeman
Soria R.G., Pascual M.S., Cartes V.H.F. (2002). Reproductive Cycle of the Cholga Paleta, Atrina Seminuda Lamarck, 1819 (Bivalvıa: Pinnidae) From Northern Patagonia, Argentina. J. Shellfish Res. 21:479-488.
Strickland, J.D.H., Parsons, T.R. (1972). A practical handbook of seawater analysis. Fish. Res. Board Can Bull.167 p.
Talikhedkar, P.M., Mane, U.H. (1976). Salinity tolerance survival, behaviour and weight changes of the wedge clam, Donax cuneatus. J. Mar. Biol. Assoc. India. 18(3):476-487
Thayer, C.W. (1975). Morphological adaptations of benthic invertebrates to soft substrata. J. Mar. Res. 33: 177-189
Thippeswamy, S., Mohan Joseph, M. (1992). Allometry in the wedge clam, Donax incarnatus (Gmelin) from Panambur beach, Mangalore. Indian J. Mar. Sci. 21:161-163.
Tiriado, C., Salas, C. (1999). Reproduction of Donax venustus Poli 1795, Donax semistriatus Poli 1795 and Intermediate Morphotypes (Bivalvia: Donacidae) in the Littoral of Málaga (Southern Spain). Mar. Ecol. 20:111-130 https://doi.org/10.1046/j.1439-0485.1999.00068.x
Trueman, E.R., Answell, A.D. (1969). The mechanism of burrowing into soft substrata by marine animals. Oceanogr. Mar. Biol. 7:315-366.

Walne, P.R. (1976). Experiments on the culture of the Butterfish Venerupis deccussata L. Aquac. 8: 371–381. https://doi.org/10.1016/0044-8486(76)90119-8.
Yıldız, H., Lök, A., Acarlı, S., Serdar, S., Küçükdermenci, A., Berber, S., Vural, P. (2013) Influences of different collector materials on Mediterranean Mussel, Mytilus galloprovincialis L. 1819 in the Dardanelles. Mar. Sci. Technol. Bull. 2(1): 23-35.
Yıldız, H., Palaz, M., Bulut, M. (2006). Condition indices of Mediterranean mussels (Mytilus galloprovincialis L. 1819) growing on suspended ropes in Dardanelles. J. Food Technol. 4(3): 221-224.
Yılmazer, N. (2005). Donax trunculus (Bivalvia: Donacidae) ovaryumunun morfolojisi ve oogenezinin ince yapısı. Istanbul University. Institute of sciences. PhD thesis. 116 p (in Turkish)
Yiğitkurt, S. (2021). Reproductive biology of the rayed pearl oyster (Pinctada imbricata radiata, Leach 1814) in Izmir Bay. Oceanol. Hydrobiol. Stud. 50(1):87-97. https://doi.org/10.2478/oandhs-2021-0009.
Yiğitkurt S., Lök A., Kırtık A., Acarlı S., Kurtay E., Küçükdermenci A., Durmaz Y. (2020). Spat efficiency in the pearl oyster Pinctada radiata (Leach, 1814) in the surface and bottom water at Karantina Island. Oceanol. Hydrobiol. Stud. 49(2):184-192. https://doi.org/10.1515/ohs-2020-0017
Zeichen, M.M., Agnesi, S., Mariani, A., Maccaroni, A., Ardizzone, G.D. (2002). Biology and population dynamics of Donax trunculus L. (Bivalvia: Donacidae) in the South Adriatic coast (Italy). Estuar. Coast. Shelf Sci. 54:971–982. https://doi.org/10.1006/ecss.2001.0868

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

A cost-effective alternative to standard medium enhances the pigment production and antibacterial activity of *A. platensis*

Muazzez Gürgan Eser[1*], Çetin Yağcılar[1], Aslı Mutluç[1]

Abstract: Spirulina (*Arthrospira platensis*) is a microalga with a high value due to the bioactive compounds it possesses. It has many applications in various industries such as food, pharmaceuticals and dye industries. Replacing the standard growth medium for Spirulina with a more cost-effective alternative would offer a more sustainable production of microalgae. That is why in this study, there different growth media [standard Zarrouk's medium (ZM), Low Medium (LM) and Modified Low medium (MLM)] were tested in 5L bioreactors and bioactive compounds (chlorophyll a, chlorophyll b, total chlorophyll, carotenoid and phycocyanin) in Spirulina were measured. Elemental analysis of the biomass was carried out by ICP-OES, and antibacterial activity of Spirulina extracts were analyzed. The results showed that the bioactive compound contents in Spirulina were elevated upon cultivation in MLM, which increased the antibacterial activity of the extracts. The lack of chelators in MLM significantly decreased the cost of the medium. Moreover, higher production of pigments suggested that there was no need to use high-cost micronutrient solutions for the aim of pigment production, which definitely lowered the cost of the medium. As a result, enhanced bioactive compound production on MLM compared to ZM and LM increases the economic value of the microalgae. Both reduced costs and increased bioactive compound contents make MLM a better choice for Spirulina production

Keywords: *Arthrospira platensis*, growth medium, phycocyanin, carotenoid, chlorophyll, antibacterial activity

Standart besiyerine alternatif uygun maliyetli besiyeri *A. platensis*'in pigment üretimini ve antibakteriyel aktivitesini artırmaktadır

Özet: Spirulina (*Arthrospira platensis*), sahip olduğu biyoaktif bileşikler nedeniyle yüksek katma değere sahip bir mikro algdir. Spirulina süper gıda ve geleceğin gıdası olarak kabul edilmektedir. Gıda, ilaç ve boya endüstrileri gibi çeşitli sektörlerde birçok uygulama alanına sahiptir. Spirulina için standart büyüme ortamının daha uygun maliyetli bir alternatifle değiştirilmesi, daha sürdürülebilir bir mikroalg üretimi sağlayacaktır. Bu nedenle bu çalışmada, farklı büyüme ortamları [standart Zarrouk ortamı (ZM), Low Medium (LM) ve Modified Low medium (MLM)] 5L biyoreaktörlerde test edilmiş ve Spirulina'daki biyoaktif bileşikler (klorofil a, klorofil b, toplam klorofil, karotenoid ve fikosiyanin) ölçülmüştür. Biyokütlenin element analizi ICP-OES ile gerçekleştirilmiş ve Spirulina ekstraktlarının antibakteriyel aktivitesi analiz edilmiştir. Sonuçlar, Spirulina'daki biyoaktif bileşik içeriklerinin MLM'de yetiştirildiğinde arttığını ve bunun da ekstraktların antibakteriyel aktivitesini artırdığını göstermiştir. MLM'de şelatör bulunmaması ortamın maliyetini önemli ölçüde azaltmıştır. Ayrıca, daha yüksek pigment üretimi, pigment üretimi amacıyla yüksek maliyetli mikro besin çözeltisi kullanılmasına gerek olmadığını göstermiş ve bu da ortam maliyetini ciddi anlamda düşürmüştür. Sonuç olarak, MLM'de ZM ve LM'ye kıyasla daha fazla biyoaktif bileşik üretimi mikroalglerin ekonomik değerini artırmaktadır. Hem azalan maliyetler hem de artan biyoaktif bileşik içerikleri MLM'yi Spirulina üretimi için daha iyi bir seçim haline getirmektedir.

Anahtar Kelimeler: *Arthrospira platensis*, büyüme ortamı, fikosiyanin, karotenoid, klorofil, antibakteriyel aktivite

Article Info (Research)

1 Tekirdağ Namık Kemal University, Faculty of Arts and Sciences, Department of Biology Tekirdağ/Türkiye
***Corresponding Author:** mgurgan@nku.edu.tr

Citation: Eser, M.G., Yağcılar, Ç., Mutluç, A. (2025), A cost-effective alternative to standard medium enhances the pigment production and antibacterial activity of *A. platensis*, MEMBA Water Sciences Journal, 11, (2) 224-233.
https://doi.org/10.58626/memba.1648019

Submission Date: 27 February 2025
Acceptance Date: 19 June 2025
Publishing Date: 28 June 2025

1. Introduction

Microalgae are considered as a sustainable nutritional source to meet the requirements of the growing population. Besides being used as nutritional supplements, they are also used in food industry and for green energy production (Nethravathy et al., 2019; Rahman et al., 2017; Zhang et al., 2022). The biomass composition and growth of microalgae vary greatly depending on a number of environmental factors, but light, the availability of suitable nutrients and temperature are the most important of these factors (Ragaza et al., 2020). *Arthrospira platensis*, well known as Spirulina, is a cyanobacterium naturally living in water ecosystems (Vo et al., 2015). The chemical composition of Spirulina microalgae in dry weight consists of 60-70% proteins, carbohydrates, various vitamins such as provitamin A, vitamin C, vitamin E, as well as minerals including iron, calcium, chromium, copper, magnesium, manganese, phosphorus, potassium, sodium, and zinc. The optimum growth of these microalgae under laboratory conditions can be achieved within a temperature range of 30-35 ℃ and a broad pH range of 8.5 to 11 (Soni et al., 2017). Spirulina is a photosynthetic organism that uses light energy to synthesize organic molecules and can be cultivated in various water sources (Benelhadj et al., 2016). Spirulina is recognized as one of the most widely cultivated microalgae globally due to its positive impacts on health and its extensive applications in the food, cosmetics, and pharmaceutical industries. It is suggested to be used for development of novel functional foods (Lafarga et al., 2020; Soni et al., 2019). Due to its rich nutritional components such as high protein (70%), high fatty acid content (18-22%), antioxidants, pigments, vitamins (vitamin A, B1, B2, B3, B6, B9, B12, C, D, E), minerals such as calcium, magnesium, phosphorus, iron, selenium and zinc, it has become a popular dietary supplement (Benelhadj et al., 2016; Vo et al., 2015; Vonshak, 1997) Bioactive compounds like unsaturated fatty acids, carotenoids, chlorophylls, phenolic compounds and phycobiliproteins are responsible for Spirulina's antioxidant, anticancer, probiotic, and anti-inflammatory properties (Bortolini et al., 2022). There is growing attention on consumption of Spirulina as functional food around the world. The Spirulina market is projected to be more than 1 billion USD in the next few years (Singh, 2021). In food manufacturing, the demand for food ingredients derived from natural sources has increased and the search for innovative functional foods and nutraceuticals is progressing under the guidance of biotechnological developments (Sahil et al., 2024). Thus, microalgae play an important role in this process due to their high nutritional content and biological activities. For large scale production of algal biomass, the illumination, temperature arrangement and medium will be the main sources of cost together with the downstream processing. Currently, the most common and standard medium to cultivate Spirulina is Zarrouk's medium. The research on evaluating waste materials and other media is a novel concept to minimize the costs of algal production. Although the standard Zarrouk's medium used in microalgae production is preferred to ensure high quality biomass production, the sodium nitrate used as a nitrogen source is a factor effective on high costs (Uba et al., 2024). To reduce the nutrient costs, it is therefore necessary to use less expensive chemicals. However, standard Zarrouk's medium contains a variety of chemicals. Therefore, nutrient chemical substitutions are thought to be effective to reduce the costs (Claude et al., 2023; Rahim et al., 2021). Although waste materials such as wastewaters tend to reduce productivity, low-cost media designed to enhance Spirulina's productivity should be developed to achieve more economical production (Lim et al., 2021). The primary aim of this study is to investigate the effectiveness of culture media that are not only lower in cost compared to Zarrouk's medium but also possess higher efficiency in achieving the desired outcomes.

2. Materials and Methods

Arthrospira platensis was commercially obtained from a local provider (NS Spirulina, Türkiye). In order to test the purity of the culture, the culture was spread on agar plates of Zarrouk's medium (ZM) (Table 1) to which 1.5 g/L agar was added and sterilized at 121℃ at 1.5 atm for 20 minutes. The micronutrient solution was prepared and mixed with the sterilized Zarrouk's medium via filter sterilization using a sterile filter (22 μm pore size). A single colony of *A. platensis* was chosen and grown in sterile ZM solution until sufficient amount of Spirulina culture was obtained.

In order to test the growth performances of different culture media for *A. platensis*, three different media were prepared with the constituents given in Table 1. The formulations of Low and Modified Low Media have been designed by the authors. Cylindrical plastic culture boxes of 5L volume were used with a working volume of 4500 mL. A volume of 250 mL *A. platensis* culture from the starting culture with optical density 2.5 at 565 nm was added to the reactor at the beginning of the experiment. The reactors were illuminated with warm white LEDS. The cultures were prepared in 5 replicate reactors. The light intensity provided was around 20.000 lux, the ambient temperature was 36-37 ℃, while the culture temperatures were 31-32 ℃, the ambient humidity was 34-35% throughout the experiment. The total dissolved solids were 10+, EC was 20+, and saltiness was 10+ for all the conditions. Daily, spectrophotometric measurements were carried out.

Table 1. Compositions of Zarrouk's Medium (ZM), Low Medium (LM) and Modified Low Medium (MLM)

	Zarrouk's Medium (ZM)	Low Medium (LM)	Modified Low Medium (MLM)
$NaHCO_3$ (g)	16.8	80.0	100.0
$NaNO_3$ (g)	2.5	-	-
KNO_3 (g)	-	10	12
K_2HPO_4 (g)	0.5	-	-
$(NH_4)_3PO_4$ (g)	-	0.5	0.5
K_2SO_4 (g)	1.0	2.5	0.25
NaCl (g)	1.0	5.0	5.0
$MgSO_4.7H_2O$ (g)	0.2	0.5	0.25
$CaCl_2.2H_2O$ (g)	0.04	0.5	0.5
$FeSO_4.7H_2O$ (g)	0.01	-	0.05
$Fe(OH)_2$	-	1 drop	-
EDTA (g)	0.08	-	-
Micronutrient solution	1mL	-	-

Micronutrient solution: H_3BO_3: 2.86 g/L, $MnCl_2.4H_2O$: 1.81 g/L, $ZnSO_4.4H_2O$: 0.222 g/L, Na_2MoO_4: 0.0177 g/L, $CuSO_4.5H_2O$: 0.079 g/L

Following the inoculations to culture media, pH and total dissolved solids (TDS) were measured using a pH meter (Extech ExStik®II) and temperature, salinity (ppt) and conductivity (mS/cm) were determined by the help of the Extech pH100 device. The light intensity was measured using UT 383 Mini Lux Meter, and HTC-1 device was used to record the ambient temperature. On a daily basis, the biomass concentration of Spirulina was measured at 565 nm using a spectrophotometer (Shimadzu UVmini-240). The chlorophyll a content in the culture was measured at 680 nm and the optical density of the culture was measured at 750 nm using a spectrophotometer. When the pH of the cultures reached 10, *A. platensis* cultures were harvested by filtering through silk tammy cloth followed by washing 2-3 times with distilled water. Fresh weight of the harvest was measured on a scale. The harvested Spirulina was spread on glass plates and let to dry for 12 hours at 30-40 ℃ under infrared lamp. The dried Spirulina biomass was used to measure chlorophyll, carotenoid, phycocyanin and elemental contents, and antibacterial activity tests.

2.1. Chlorophyll analysis

Ethanol (95%) and dry Spirulina were mixed at a ratio of 1:20 (m/V). The mixture was kept at 4℃ overnight and then centrifuged at 10.000 rpm for 5 minutes. The supernatant was taken into another microcentrifuge tube, and the absorbance of the supernatant was measured at 649 664 and 470 nm. The following formulas were used to calculate chlorophyll *a*, chlorophyll *b* and carotenoid concentrations (Claude et al., 2023; Sumanta et al., 2014)**.**

$$Chlorophyll\ a\ (mgL^{-1}) = 13.3\ \times\ A_{664} - 5.19\ \times A_{649} \tag{1}$$

$$Chlorophyll\ b\ (mgL^{-1}) = 27.43\ \times A_{649} - 8.12\ \times A_{664} \tag{2}$$

$$Total\ Chlorophyll\ (mgL^{-1}) = Chla + Chl\ b \tag{3}$$

$$Total\ carotenoid\ (mg\ L^{-1}) = \left((1000\ \times A_{470} - 2.13 \times chla - -97.63 \times chlb)\right) \div 209 \tag{4}$$

2.2. Phycocyanin analysis

Distilled water was mixed with dry Spirulina at 1:30 (m/V). The mixture was kept at -20℃ overnight, Then the mixture was thawed, mixed homogeneously and filtered through filter paper. The absorbance of the filtrate was measured at 615 and 652 nm. The following formula was used to determine the phycocyanin concentration of Spirulina (Bennett and Bogobad, 1973).

$$Phycocyanin(mg/ml) = ((A_{615}) - (0.474 \times A_{652})) \div 5.34 \quad (5)$$

2.3. Elemental analysis

The elemental analysis of the dry biomass of Spirulina was carried out in Tekirdağ Namık Kemal University Central Research Laboratory using Inductively coupled plasma-optical emission spectrometry (ICP-OES) (Agilent 700, Agilent) according to (Kacar and İnal, 2010). The details of ICP-OES parameters are as given by (Adiloğlu, 2021).

2.4. Obtaining extracts of Spirulina

Extracts of Spriulina were obtained using different solvents (distilled water, ethanol, methanol, acetone, and ethyl acetate). 1000 µL of solvent was added on 0.1 g of Spirulina and kept at 40℃ for 24 hours. The mixture was mixed from time to time during the incubation period. The mixture was later filtered through filter paper and the solvent was evaporated in the hood. The dried extract was dissolved using 1000 µL DMSO which is known to have no antibacterial effect (Ozturk et al., 2019, 2021).

2.4. Antibacterial activity testing

The bacteria used in this study were *Escherichia coli* ATCC 25922, *Pseudomonas aeruginosa* ATCC 27853, *Staphylococcus aureus* ATCC 29213 and *Enterococcus faecalis* ATCC 29212 were obtained from Turkish Republic General Directorate of Public Health, Ankara, Turkey. The bacteria were first grown on Tryptic soy agar, then bacterial concentrations were adjusted to 0.5 McFarland using sterile isotonic solution (NaCl 0.9%). The bacterial solutions were spread on Mueller Hinton agar followed by opening 8 mm of wells under aseptic conditions. 100 µL of each microalgae extract were added to the wells, and plates were kept at 37℃ for 24 h. The diameter of zones formed around the wells were measured with an electronic compass.

The data obtained were analyzed with one-way analysis of variance (ANOVA) (Girden, 1992) in Minitab 12 software.

3. Results and Discussion

In this study, Low medium and Modified Low media were tested as cheaper alternatives to the standard Zarrouk's medium for growth of *A. platensis* (Yap, Jain, and Trau 2018). The two alternative formulations (LM and MLM) have been designed to lack $NaNO_3$ and K_2HPO_4 since these are costly ingredients and not very easy to obtain. However, $NaHCO_3$ is quite cheap and easy to obtain. Since the main ingredient for Spirulina cultivation is Na, the sodium in the new formulations is replaced with the cheap alternative. The biomass changes over 14 days of cultivation, through measuring OD at 565 nm (Yap et al. 2018), is shown in Figure 1. The biomass of Spirulina grown in Modified Low Medium was higher, particularly higher than the standard Zarrouk's Medium. The fresh and dry weights (108.8 ±4.7 g fresh and 7.14 ± 0.2 g dry weight) at the end of the experiment was however lower for MLM than other two other media. The highest weights were obtained on LM (161.4 ±13.3 fresh weight and 8.2 ± 0.2 g dry weight), followed by ZM (120.3 ± 7.7 g fresh weight, and 8.3 ± 0.3 g dry weight). The reason for significant difference might be the harvesting method, which is done with the help of a silk tammy cloth, where some spirulina kept on the cloth. Unlike fresh biomass, the dry biomasses obtained in this study from ZM and LM were not significantly different from each other, but higher than MLM.

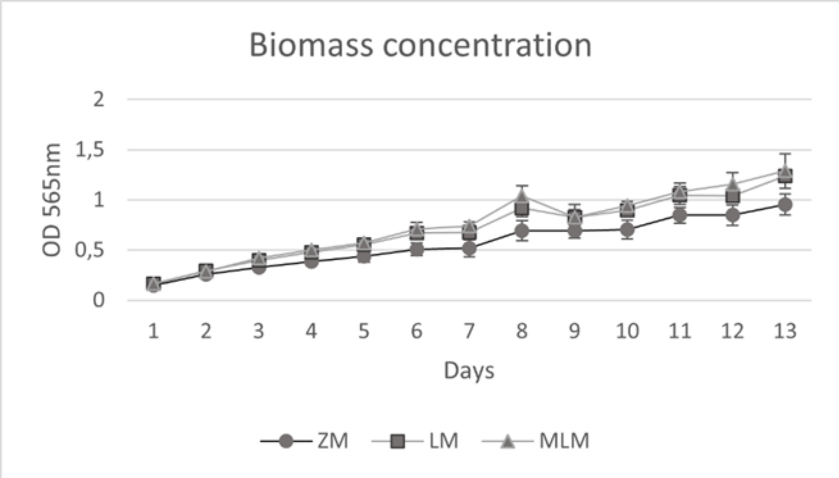


Figure 1. The biomass of *A. platensis* grown in standard Zarrouk's medium (ZM), Low medium (LM) and Modified Low Medium (MLM).

Harvest yield is an important factor but not the only aim of Spirulina production. Spirulina is a significant source of bioactive components such as chlorophylls, carotenoid and phycocyanin. The amounts of phycocyanin, carotenoid and chlorophyll of Spirulina grown in different media are measured and given in Table 2.

Table 2. The concentrations of some compounds of *A. platensis* grown in standard Zarrouk's medium (ZM), Low medium (LM) and Modified Low Medium (MLM).

	Chlorophyll *a* (mg/L)	Chlorophyll *b* (mg/L)	Total chlorophyll (mg/L)	Phycocyanin (mg/mL)	Carotenoid (mg/L)
ZM	91.84 ± 12.4	21.67±1.91	123.57±25.06	0.47 ± 0.08	21.78 ± 11.24
LM	21.49 ± 4.03	3.61 ± 0.95	25.10±4.85	0.64 ± 0.04	3.11 ± 0.62
MLM	95.05 ± 4.78	35.41 ± 10.52	143.04±19.45	1.24 ± 0.12	28.95 ± 11.24
P value	0.000	0.002	0.000	0.000	0.017

The values are given as mean ± standard error of three replicates

Chlorophyll *a* and chlorophyll *b* concentration of MLM significantly higher than the others (p=0.000). Also in total, the highest chlorophyll value was observed for Spirulina grown in MLM (p=0.000) (Table 2). Both chlorophyll molecules take part in photosynthesis, chlorophyll *a* being the main molecule, while chlorophyll *b* is the accessory protein. Chlorophylls are essential for pharmaceutical and food industry (Sun et al., 2023) and it has been shown that microalgal chlorophyll activity is higher than plant chlorophylls (Patel et al., 2022). Moreover, the amount of chlorophyll found in Spirulina biomass is more than ten times that in plants, such as spinach (Gross, 2012). Therefore, using a cheaper growth medium alternative with a higher yield of chlorophylls is very advantageous especially for industrial applications.

The phycocyanin concentration of Spirulina grown in MLM medium was significantly higher than the other two media, in particular more than twice of that Zarrouk's Medium (p=0.000) (Table 2). Phycocyanin is a blue color pigment found in blue green algae. The colorant of phycocyanin is very stable in a high range of pH (5-8) which can make it valuable for industrial applications (Chethana et al., 2015). Apart from being a colorant, phycocyanin has worthwhile health benefits due to its antioxidant, antitumor, neuroprotective etc. effects (Abdel-Daim et al., 2015; Liu et al., 2020; Romay et al., 2003). Using a cheaper alternative for algal growth to the most common spirulina medium in this study resulted in higher phycocyanin content which enhances its health benefits.

The other pigments produced by Spirulina are carotenoids. They are responsible for the color of the microalgae as well as being a crucial molecule in photosynthesis and photoprotection (Masojídek, Torzillo, and Koblízek, 2013; Park et al., 2018). They are important sources for the food industry such as colorants, for flavoring and also as nutritional supplements for provitamin A source (Kirsten and Roge, 2015). Like other pigments, carotenoids bear considerable health benefits such as protecting against cardiovascular diseases, against cancer and aging (Tapiero, Townsend, and Tew, 2004). In this study, the amount of carotenoid produced by Spirulina was significantly enhanced by the Modified Low Medium (p=0.017) (Table 2). Hence, Modified Low medium was shown to be effective in enhancing the production of bioactive pigments of Spirulina which increases the health benefits and industrial value.

In order to further analyze the Spirulina produced in this study, elemental analysis of the biomass was carried out using ICP-OES. The results are given in Table 3.

Table 3. Elemental analysis of *A. platensis* grown in standard Zarrouk's Medium (ZM), Low Medium (LM) and Modified Low Medium (MLM).

	ZM	LM	MLM	P value
Na (%)	3.24 ± 0.01	2.87± 0.01	1.38± 0.02	0.000
P (%)	2.64±0.01	1.22± 0.002	1.37±0.01	0.000
K (%)	0.89±0.004	1.12±0.03	0.72±0.004	0.001
Ca (%)	1.40±0.02	2.16±0.10	1.93±0.02	0.002
Mg (%)	1.47±0.01	1.14±0.04	1.25±0.01	0.002
Fe (ppm)	1160.5±7.7	73.0±0.3	1147.5±15.6	0.000
Cu (ppm)	14.83±0.43	6.89±0.23	2.33±0.68	0.000
Zn (ppm)	20.99±1.01	17.66±0.23	18.24±0.28	0.024
Mn (ppm)	27.06±0.60	7.66±0.03	19.54±0.40	0.001
B (ppm)	69.41±9.92	108.03±5.66	2.33±0.68	0.000

Elemental composition of the biomass is critical to have an insight about the metabolism and pigment production of Spirulina. Some elements such as Mg play a crucial role in chlorophyll synthesis as it is the central atom in the chlorophyll structure, and also for other important molecules (Masojídek et al. 2013; Pohland and Schneider 2019). The composition of the media has a significant impact on the elemental composition of the final biomass. It is noteworthy to mention the concentrations of the micronutrient elements Fe, Cu, Mn and B (Table 3). The elements, P, K, Ca, Na and Ca are macro nutrient elements, which are required to produce major molecules in cells, such as proteins, nucleic acids, lipids, etc., with H, O and C. Micronutrients, on the other hand, have crucial roles in the metabolism such as being cofactors of enzymes, and are found in very low concentrations in the cells. In MLM a 5 times higher Fe source was used ($FeSO_4.7H_2O$) which did not increase the Fe in the biomass. The lack of EDTA might be a reason for the indifference. In attempts to reduce the cost of growth media, even using five times more $FeSO_4.7H_2O$ concentration costs almost 3.4 times less than using EDTA. This itself can lower the cost of growth medium of Spirulina.

$Fe(OH)_2$ solution has been used instead of powder $FeSO_4.7H_2O$ in Low medium, as the latter is more expensive than the solution. Moreover, in ZM, EDTA was used to chelate iron. On the other hand, in LM, $Fe(OH)_2$ seems to be a less efficient Fe source as there was no EDTA in the medium, as Fe in biomass grown in LM was the lowest, almost 15 times less (Table 3). But in order to avoid the expensive EDTA, more iron powder was used, and still it was cheaper than using EDTA. When the elemental analysis is investigated, almost the same amount of Fe was found in Spirulina between ZM and MLM. This way, we achieved to avoid EDTA and make the cells have the same amount of iron. Apparently, there were three Na sources in ZM (Table 1) which resulted in higher Na in biomass. In ZM, there was an additional micronutrient solution added which was source of B, Mn, Zn, Cu and Mo, which should be the reason for higher Zn, Mn and Cu concentration in biomass grown in ZM. (Table 3). If the ultimate aim of Spirulina cultivation is to obtain higher pigments, then Modified Zarrouk's medium which does not contain the costly micronutrient solution, can be used instead of Zarrouk's medium. Since pigments of Spirulina are valuable for industrial applications, higher pigment production can be achieved with a cheaper alternative to standard Zarrouk's medium.

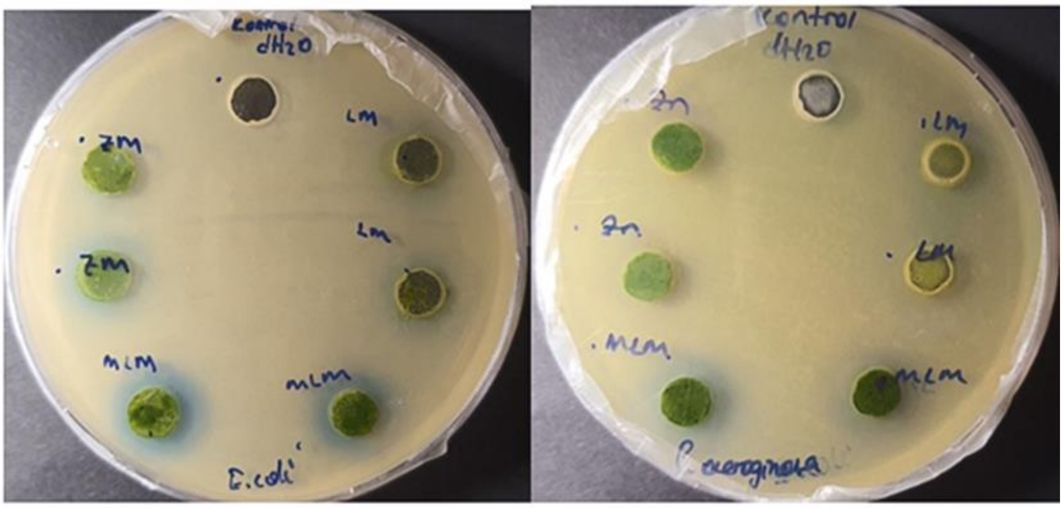


Figure 2. Antibacterial activity testing of Spirulina grown in ZM, LM and MLM culture media.

Table 4. Zone diameter of Spirulina extracts on different bacteria

	Zarrouk Medium	LM Medium	MLM Medium	Gentamicin*	P value
E. coli	13.95±0.21	15.65±1.48	16.10±0.28	16	0.174
P. aeruginosa	14.30±1.13	18.35±0.07	23.65±2.19	22	0.016
S. aureus	14.70±0.14	14.45±0.07	15.55±0.07	20	0.003
E. faecalis	16.15±0.21	14.10±0.14	14.20±0.42	19	0.009

The zone diameters were given as mean±standard deviation of two replicates. *Gentamicin zone diameters according to EUCAST (2019).

In order to investigate whether changing the growth medium affects the antibacterial activity of Spirulina, extracts of Spirulina were obtained by maceration for 24 hours. No antibacterial activity was observed for the extracts of ethanol, methanol, ethyl acetate and acetone. However, only antibacterial activity was observed for distilled water extract. (Nabti et al., 2023) observed a high antibacterial activity of Spirulina with acetone extraction, however they have tried extract with a ratio of 1:1.5 dry biomass:solvent for 1 hour. In our study, the ratio was 1:20 for the solvent to surround the biomass and the mixture was kept for 24 hours. This way the cells of Spirulina are thought to lose their integrity in acetone, ethanol, ethyl acetate and methanol. However, distilled water extracts exerted antibacterial activities against the Gram positive and Gram negative bacteria tested in this study.

The antibacterial effects of Spirulina grown in different culture media on *E. coli* were not significantly different from each other. However, the antibacterial activity of Spirulina grown in Modified Low Medium (MLM) was significantly higher on *P. aeruginosa* and *S. aureus* than those grown on other culture media. This difference can be attributed to the phycocyanin of Spirulina grown in MLM. Phycocyanin content of Spirulina grown in MLM was almost twice of Spirulina grown in LM, and more than 2.5 times that on standard ZM (Table 2). Blue color around the zones indicates phycocyanin. As seen in Figure 2, both the blue zones and the clearance around the wells were higher for MLM. Chlorophyll a was also much higher in Spirulina grown in MLM than the others. Crude phycocyanin extract was found to be ineffective against *E. faecalis* by (Mohamed et al., 2018).

In our study, distilled water dissolved some of the phycocyanin in Spirulina biomass, hence we observed higher antibacterial activity compared to the previous studies.

4. Conclusion

In this study, a newly formulated growth medium for Spirulina cultivation was evaluated for bioactive compound production. The new medium modified Low medium (MLM) did not contain sodium nitrate, EDTA and micronutrient solution, which significantly lowered the cost. However, the production of pigments which are bioactive compounds was higher than the standard media. The more bioactive compounds in Spirulina, the higher the added value of the product. Besides the cost efficiency, enhanced pigment production increased the value for health benefits and industrial purposes. Therefore, Modified Low medium (MLM) can be well suggested as a cheaper alternative to Zarrouk's and Low media.

5. Compliance with Ethical Standard

a) Author Contributions

1. MGE: Experimental and statistical analyses, writing- review and editing.
2. ÇY: Conceptualization, experimental design, supervision
3 AM: Conducting experiments, experimental analyses. The published version of the manuscript has been read and approved by both authors.

b) Conflict of Interests

There is no conflict of interest, according to the authors.

c) Statement on the Welfare of Animals

Not relevant

d) Statement of Human Rights

There are no human subjects in this study.

e) Funding

This study did not obtain any financial support.

6. References

Abdel-Daim, M. M., Farouk, S. M., Madkour, F. F., & Azab, S. S. (2015). Anti-inflammatory and immunomodulatory effects of *Spirulina platensis* in comparison to *Dunaliella salina* in acetic acid-induced rat experimental colitis. *Immunopharmacology and Immunotoxicology*, *37*(2), 126–139. https://doi.org/10.3109/08923973.2014.998368

Adiloğlu, S. (2021). Relation of chelated iron (EDDHA-Fe) applications with iron accumulation and some plant nutrient elements in basil (*Ocimum basilicum* L.). *Polish Journal of Environmental Studies*, *30*(4), 3471–3479. https://doi.org/10.15244/pjoes/128736

Benelhadj, S., Gharsallaoui, A., Degraeve, P., Attia, H., & Ghorbel, D. (2016). Effect of pH on the functional properties of *Arthrospira* (*Spirulina*) *platensis* protein isolate. *Food Chemistry*, *194*, 1056–1063. https://doi.org/10.1016/J.FOODCHEM.2015.08.133

Bennett, A., & Bogobad, L. (1973). Complementary chromatic adaptation in a filamentous blue-green alga. *The Journal of Cell Biology*, *58*(2), 419–435. https://doi.org/10.1083/JCB.58.2.419

Chethana, S., Nayak, C. A., Madhusudhan, M. C., & Raghavarao, K. S. M. S. (2015). Single step aqueous two-phase extraction for downstream processing of C-phycocyanin from *Spirulina platensis*. *Journal of Food Science and Technology*, *52*(4), 2415–2421. https://doi.org/10.1007/S13197-014-1287-9

Claude, S., Oscar, W. F., Laure, N. N. P., Rodrigue, M. P. F., Lucinda, M. N. M., Kennedy, T. D., Emile, M., & Gustave, L. L. (2023). Enhanced *Spirulina platensis* growth for photosynthetic pigments production in oil palm empty fruit bunch medium. *International Journal of Sustainable Agricultural Research*, *10*(2), 52–63. https://doi.org/10.18488/ijsar.v10i2.3364

EUCAST. (2019). *The European Committee on Antimicrobial Susceptibility Testing. Breakpoint tables for interpretation of MICs and zone diameters. Version 9.0*.

Girden, E. R. (1992). ANOVA: Repeated measures. In *ANOVA: Repeated measures.* Sage Publications, Inc.

Gross, J. (2012). *Pigments in Vegetables: Chlorophylls and Carotenoids*. Springer.

Kacar, B., & İnal, A. (2010). *Plant Analyses*. Nobel Akademik Yayıncılık.

Kirsten. H, & Roge. H. (2015). Microalgal Classification: Major Classes and Genera of Commercial

Microalgal Species. In S.-K. Kim (Ed.), *Handbook of Marine Microalgae. Biotechnology Advances.* Academic Press. http://www.sciencedirect.com:5070/book/9780128007761/handbook-of-marine-microalgae

Lafarga, T., Fernández-Sevilla, J. M., González-López, C., & Acién-Fernández, F. G. (2020). Spirulina for the food and functional food industries. *Food Research International*, *137*, 109356. https://doi.org/10.1016/J.FOODRES.2020.109356

Lim, H. R., Khoo, K. S., Chew, K. W., Chang, C. K., Munawaroh, H. S. H., Kumar, P. S., Huy, N. D., & Show, P. L. (2021). Perspective of Spirulina culture with wastewater into a sustainable circular bioeconomy. *Environmental Pollution*, *284*, 117492. https://doi.org/10.1016/J.ENVPOL.2021.117492

Liu, Z., Chen, B., Wang, L. ao, Urbanovich, O., Nagorskaya, L., Li, X., & Tang, L. (2020). A review on phytoremediation of mercury contaminated soils. *Journal of Hazardous Materials*, *400*, 123138. https://doi.org/10.1016/J.JHAZMAT.2020.123138

Masojídek, J., Torzillo, G., & Koblízek, M. (2013). Photosynthesis in Microalgae. In A. Richmond & Q. Hu (Eds.), *Handbook of Microalgal Culture: Applied Phycology and Biotechnology: Second Edition* (pp. 21–36). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118567166.CH2

Mohamed, S. A., Osman, A., Abo Eita, A., & Sitohy, M. Z. (2018). Estimation of antibacterial and antioxidant activities of phycocyanin isolated from Spirulina. *Zagazig Journal of Agricultural Research*, *45*(2), 657–666. https://doi.org/10.21608/ZJAR.2018.49187

Nabti, B., Bammoune, N., Meliani, H., & Stambouli, B. (2023). Antioxidant and antimicrobial activities of Spirulina from the region of Tamanrasset, Algeria. *Journal of Herbal Medicine*, *41*, 100748. https://doi.org/10.1016/J.HERMED.2023.100748

Nethravathy, M. U., Mehar, J. G., Mudliar, S. N., & Shekh, A. Y. (2019). Recent Advances in Microalgal Bioactives for Food, Feed, and Healthcare Products: Commercial Potential, Market Space, and Sustainability. *Comprehensive Reviews in Food Science and Food Safety*, *18*(6), 1882–1897. https://doi.org/10.1111/1541-4337.12500

Ozturk, I. I., Sirinkaya, E. T., Cakmak, M., Gürgan, M., Ceyhan, D., Panagiotou, N., & Tasiopoulos, A. J. (2021). Structural and biological features of bismuth(III) halide complexes with heterocyclic thioamides. *Journal of Molecular Structure*, *1227*, 129730. https://doi.org/https://doi.org/10.1016/j.molstruc.2020.129730

Ozturk, I. I., Yarar, S., Gürgan, M., Ceyhan, D., Banti, C. N., Hadjikakou, S. K., Manoli, M., Moushi, E., & Tasiopoulos, A. J. (2019). Synthesis, characterization and biological evaluation of novel antimony(III) iodide complexes with tetramethylthiourea and N-ethylthiourea. *Inorganica Chimica Acta*, *491*. https://doi.org/10.1016/j.ica.2019.03.020

Park, W. S., Kim, H. J., Li, M., Lim, D. H., Kim, J., Kwak, S. S., Kang, C. M., Ferruzzi, M. G., & Ahn, M. J. (2018). Two Classes of Pigments, Carotenoids and C-Phycocyanin, in Spirulina Powder and Their Antioxidant Activities. *Molecules : A Journal of Synthetic Chemistry and Natural Product Chemistry*, *23*(8). https://doi.org/10.3390/MOLECULES23082065

Patel, A. K., Albarico, F. P. J. B., Perumal, P. K., Vadrale, A. P., Ntan, C. T., Chau, H. T. B., Anwar, C., Wani, H. M. ud din, Pal, A., Saini, R., Ha, L. H., Senthilkumar, B., Tsang, Y. S., Chen, C. W., Dong, C. Di, & Singhania, R. R. (2022). Algae as an emerging source of bioactive pigments. *Bioresource Technology*, *351*. https://doi.org/10.1016/J.BIORTECH.2022.126910

Pohland, A. C., & Schneider, D. (2019). Mg2+ homeostasis and transport in cyanobacteria - at the crossroads of bacterial and chloroplast Mg2+ import. *Biological Chemistry*, *400*(10), 1289–1301. https://doi.org/10.1515/HSZ-2018-0476/MACHINEREADABLECITATION/RIS

Ragaza, J. A., Hossain, M. S., Meiler, K. A., Velasquez, S. F., & Kumar, V. (2020). A review on Spirulina: alternative media for cultivation and nutritive value as an aquafeed. *Reviews in Aquaculture*, *12*(4), 2371–2395. https://doi.org/10.1111/RAQ.12439

Rahim, A., Çakir, C., Ozturk, M., Şahin, B., Soulaimani, A., Sibaoueih, M., Nasser, B., Eddoha, R., Essamadi, A., & El Amiri, B. (2021). Chemical characterization and nutritional value of *Spirulina platensis* cultivated in natural conditions of Chichaoua region (Morocco). *South African Journal of Botany*, *141*, 235–242. https://doi.org/10.1016/J.SAJB.2021.05.006

Rahman, M. A., Aziz, M. A., Al-khulaidi, R. A., Sakib, N., & Islam, M. (2017). Biodiesel production from microalgae Spirulina maxima by two step process: Optimization of process variable. *Journal of Radiation Research and Applied Sciences*, *10*(2), 140–147. https://doi.org/10.1016/J.JRRAS.2017.02.004

Romay, Ch., Gonzalez, R., Ledon, N., Remirez, D., & Rimbau, V. (2003). C-phycocyanin: a biliprotein with antioxidant, anti-inflammatory and neuroprotective effects. *Current Protein & Peptide Science*, *4*(3), 207–216. https://doi.org/10.2174/1389203033487216

Sahil, S., Bodh, S., & Verma, P. (2024). *Spirulina platensis*: A comprehensive review of its nutritional value, antioxidant activity and functional food potential. *Journal of Cellular Biotechnology*, *10*(2), 159–172. https://doi.org/10.3233/JCB-240151

Singh, S. (2021). Spirulina Market Research Report Information by Type (Arthrospira platensis, Arthrospira maxima*), By Application (Food & Beverage, Dietary Supplements, Cosmetics and Personal Care), And By Region (North America, Europe, Asia-Pasific, And Rest Of The World)-Market Forecast Till 2030.*

Soni, R. A., Sudhakar, K., & Rana, R. S. (2017). Spirulina – From growth to nutritional product: A review. *Trends in Food Science & Technology*, *69*, 157–171. https://doi.org/10.1016/J.TIFS.2017.09.010

Soni, R. A., Sudhakar, K., & Rana, R. S. (2019). Comparative study on the growth performance of *Spirulina platensis* on modifying culture media. *Energy Reports*, *5*, 327–336. https://doi.org/10.1016/J.EGYR.2019.02.009

Sumanta, N., Imranul Haque, C., Nishika, J., & Suprakash, R. (2014). Spectrophotometric Analysis of Chlorophylls and Carotenoids from Commonly Grown Fern Species by Using Various Extracting Solvents. In *Research Journal of Chemical Sciences* (Vol. 4, Issue 9).

Sun, H., Wang, Y., He, Y., Liu, B., Mou, H., Chen, F., & Yang, S. (2023). Microalgae-Derived Pigments for the Food Industry. *Marine Drugs*, *21*(2), 82. https://doi.org/10.3390/MD21020082

Tapiero, H., Townsend, D. M., & Tew, K. D. (2004). The role of carotenoids in the prevention of human pathologies. *Biomedicine and Pharmacotherapy*, *58*(2), 100–110. https://doi.org/10.1016/j.biopha.2003.12.006

Uba, K. I. N., Gaid, G. D., Perales, J. M. L., Bongga, F. C., & Gaid, R. D. (2024). From Laboratory to Production: Innovating the Small-scale Mass Production of Spirulina (*Arthrospira platensis*) with an Alternative Culture Medium and Refined Culture Conditions. *Agricultural Research*, *13*(3), 465–476. https://doi.org/10.1007/S40003-024-00709-7/TABLES/3

Vo, T.-S., Ngo, D.-H., & Kim, S.-K. (2015). Nutritional and Pharmaceutical Properties of Microalgal Spirulina. In S.-K. Kim (Ed.), *Handbook of Marine Microalgae: Biotechnology Advances* (pp. 299–308). Academic Press.

Vonshak, A. (1997). Spirulina: Growth, Physiology and Biochemistry. In A. Vonshak (Ed.), *Spirulina Platensis Arthrospira* (pp. 1–252). CRC Press. https://doi.org/10.1201/9781482272970/SPIRULINA-PLATENSIS-ARTHROSPIRA-AVIGAD-VONSHAK

Yap, P. Y., Jain, A., & Trau, D. (2018). *Determination of Biomass in Spirulina Cultures by Photopette*. www.tipbiosystems.com

Zhang, S., Zhang, L., Xu, G., Li, F., & Li, X. (2022). A review on biodiesel production from microalgae: Influencing parameters and recent advanced technologies. *Frontiers in Microbiology*, *13*, 970028. https://doi.org/10.3389/FMICB.2022.970028/BIBTEX

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

Evaluating Water Temperature Changes in Greenhouse and Non-Greenhouse Aquaculture Pond

Ünal Öz[1]*

Abstract: Greenhouse aquaculture is the subject of research for developing economic and applicable methods. This study was carried out to determine the water temperature changes in-greenhouse and out-greenhouse ponds used in aquaculture. The determined water temperature values were evaluated in terms of the cultivation of tropical freshwater aquarium fish. The research was conducted in a production facility where edible and ornamental fish were cultivated, with in-greenhouse and out-greenhouse ponds, for 48 days during the cold season. Water temperature values were measured daily. During the 48-day period between February and April in the Antalya region, the average water temperatures in-greenhouse and out-greenhouse ponds were determined as 23.53±0.16 °C and 15.37±0.16 °C, respectively, while the average in greenhouse air temperature was recorded as 28.15±0.56 °C. Statistical analysis indicated a significant difference between the average water temperatures. Considering these findings, it was determined that greenhouse-based systems play a crucial role in aquaculture, particularly for the cultivation of tropical aquarium fish.

Keywords: Aquaculture, Fish pond, Greenhouse, Water temperature

Sera ve Sera Dışı Su Ürünleri Yetiştirme Havuzlarında Su Sıcaklığı Değişimlerinin Değerlendirilmesi

Özet: Sera içi su ürünleri yetiştiriciliği ekonomik ve uygulanabilir yöntemlerin geliştirilebilmesi için araştırmalara konu olmaktadır. Bu araştırma, su ürünleri yetiştiriciliğinde kullanılan sera içi ve sera dışı havuzlardaki su sıcaklık değişimlerinin belirlenmesi için yapılmış ve belirlenen su sıcaklık değerleri tropical tatlı su akaryum balıklarının yetiştiriciliği açısından değerlendirilmiştir. Araştırma, sera içi ve sera dışı havuzları bulunan yemeklik ve süs balıkları yetiştiriciliği yapılan bir üretim tesisinde 48 gün süreyle, soğuk dönemde yürütülmüş ve günlük olarak su sıcaklık değerleri belirlenmiştir. Antalya bölgesinde Şubat ve Nisan ayları arasında 48 gün süreyle sera içi ve sera dışı havuzlarda ortalama su sıcaklık değerleri sırasıyla 23.53±0.16 °C ve 15.37±0.16 °C olarak, sera içi hava sıcaklığı ise 28.15±0.56 °C olarak belirlenmiştir. İstatiksel analiz sonucu ortalama su sıcaklıkları arasındaki farkın önemli olduğu saptanmıştır. Bu değerler göz önüne alındığında özellikle tropical akvaryum balığı türlerinin yetiştiriciliğinde sera sistemlerinin su ürünleri yetiştiriciliği için önemli bir üretim uygulaması olduğu bulgusunun desteklendiği belirlenmiştir.

Anahtar Kelimeler: Su ürünleri yetiştiriciliği, Balık havuzu, Sera sistemi, Su sıcaklığı

Article Info (Research)

[1]Sinop University, Faculty of Fisheries, Department of Hydrobiology, Sinop/Türkiye
***Corresponding Author:**
unaloz@sinop.edu.tr

Citation: Öz, Ü. (2025), Evaluating Water Temperature Changes in Greenhouse and Non-Greenhouse Aquaculture Pond, MEMBA Water Sciences Journal. 11, (2).234-241.
https://doi.org/10.58626/memba.1671274

Submission Date: 8 April 2025
Acceptance Date: 7 May 2025
Publishing Date: 28 June 2025

1. Introduction

Aquaculture is a highly valuable commercial sector. Fish farming, which dates back to ancient times, has evolved with increasing demand and technological advancements. In both edible fish and aquarium fish farming, two critical factors are the regulation of water and feeding protocols specific to the cultivated species. The fundamental criterion in managing water parameters and feeding practices is to meet the biological requirements of the target species. Water parameters and feeding procedures are interdependent and significantly influence the success of aquaculture, aiming for sustainable production conditions. Water temperature is a key factor that affects other water parameters such as pH, dissolved oxygen, and nitrogenous compounds (NH_3/NH_4+, NO_2, NO_3). Additionally, since fish are ectothermic organisms, water temperature plays a crucial role in the cultivation of aquatic species. The ornamental fish trade, a major branch of aquaculture, has grown into a multibillion-dollar industry across more than 125 countries. There are over 2.500 fish species involved in this trade, with more than 60% originating from freshwater habitats. Species such as koi and goldfish (carp species), guppy, molly, and platy (livebearers), ahli, yellow lab, and angelfish (cichlids), as well as crayfish species and various aquatic plants, are commonly produced on a commercial scale. Greenhouse ponds are particularly utilized for the cultivation of tropical species (Watson and Shireman, 2002; Li et al., 2009; Srinivasan, 2013; Mamun Siddiky and Mondal, 2016; Sirimanna and Dissanayake, 2019; Sharma, 2021).

Yongphet et al. (2016) investigated the heat preservation system of ponds inside and outside the greenhouse and the heat preservation system of the pond inside the greenhouse and determined that it is possible to increase the water temperature by integrating the greenhouse fish pond with the system that reduces heat loss.

Traditional greenhouses are primarily constructed using plastic film and wooden columns. This system is currently recognized as one of the most effective methods for improving operational performance. Research is ongoing to enhance optimal conditions in greenhouse systems, and new greenhouse techniques are being developed to regulate temperature more effectively in traditional aquaculture systems. Successful greenhouse-based aquaculture requires high wind resistance, efficient heat conservation, and reasonable costs. These requirements dictate the choice of construction materials and operational procedures (Peng et al., 2014).

Zhu et al. (1998) studied a greenhouse model to determine the thermal properties of greenhouse-covered small lake systems. This model was used to track small lake water temperature increases, compare the performance of different covering materials, and identify the primary heat flows within the system.

Sarkar and Tiwari (2006) reported their research on a thermal model for greenhouse pond systems. Klemetson and Rogers (1985) stated that a greenhouse or plastic-covered pond could increase water temperature by 2.8–4.4 °C compared to outdoor ponds throughout the year.

Greenhouse systems contribute to maintaining water temperatures within optimal ranges, particularly for the cultivation of tropical and temperate species. These systems help regulate the production cycle in terms of duration, quantity, and quality to meet market demands. As research on this topic increases, existing gaps in knowledge can be addressed, leading to more efficient production practices. In the coming years, climate changes driven by global warming are expected to heighten the demand for farmed aquatic products, thereby increasing the importance of aquaculture. Greenhouse systems, which offer advantages in controlling and optimizing environmental conditions, are also expected to play a crucial role in mitigating the impacts of climate change by maintaining stable production conditions (Öz, 2012).

Various construction materials, such as glass or plastic roofs and walls, are used in greenhouse structures. The glass or plastic covering acts as a barrier to airflow, helping retain energy within the greenhouse. While traditionally used for cultivating plants, vegetables, and flowers, greenhouses are now increasingly being utilized in aquaculture and aquaponic systems. These greenhouses require installation with heating, cooling, and lighting equipment to ensure optimal conditions. In fish farming, extremely low temperatures (e.g., 9°C) can lead to significantly reduced metabolic activity due to the ectothermic nature of fish, whereas excessively high temperatures (e.g., 45°C) can result in increased evaporation rates. Such extreme temperature variations highlight the necessity of maintaining water temperatures within ideal ranges to ensure successful aquaculture operations (Li et al., 2009; Omorodion and Madu, 2013; Mashaii et al., 2021).

Greenhouse-based aquaculture, including fish and shrimp farming, provides several advantages by mitigating adverse climatic conditions that may prevent the maintenance of optimal water temperatures for tropical and subtropical species. This system enables continuous or seasonal production, regardless of external weather conditions. Research is also being conducted to enhance the structural applications of traditional greenhouse systems to further improve their benefits (Peng et al., 2014; Akidiva et al., 2020; Mashaii et al., 2021).

Recent studies indicate that changes in rainfall, wind patterns, and temperature fluctuations can directly or indirectly impact disease outbreaks in aquatic species. Climate variability poses a significant risk to shrimp farmers, affecting production success and profitability. Compared to traditional outdoor shrimp farming, greenhouse-based shrimp farming can yield up to three production cycles per year. This makes greenhouse systems a viable option for maintaining a steady production flow throughout the year. Additionally, greenhouses can effectively protect shrimp from rainfall, reduce disease incidence, and enhance product quality. By preventing water temperatures from dropping below 18°C during winter and early spring, greenhouse systems can extend the shrimp farming season and ultimately increase profitability for aquaculture producers (Peng et al., 2014).

It is well established that fish metabolic rates and food consumption increase with water temperature. Previous studies have documented this finding (Likongwe et al., 1996; Tribeni et al., 2010; Musal et al., 2012; Hamed et al., 2021). This theory has been further validated by the observation that fish harvested from greenhouse ponds tend to be larger. Harrahy et al. (2001) suggested that lysozyme levels in most teleost fish are directly correlated with water temperature and that lower water temperatures reduce lysozyme activity. This indicates that fish raised at higher temperatures in greenhouse systems may benefit from improved immune function. Variations in greenhouse design, such as covering a larger surface area or positioning the structure closer to the water surface, may lead to more pronounced differences in temperature regulation. Consequently, further research on modifications to indoor fish pond designs, which could create thermal gradients, would be beneficial. Ideally, such interventions should be easy to implement and cost-effective, particularly for small-scale farmers in developing countries (Emam et al., 2023).

Research and experimental studies have demonstrated that greenhouses can be successfully and profitably constructed using cost-effective materials such as polyethylene, depending on their durability. Aquaculture practices are often conducted in greenhouses in arid regions where temperatures drop significantly and in extremely cold climates with harsh winters. It has been reported that, even during such unfavorable periods, fish farming and other aquaculture activities can be successfully maintained with minimal investment in greenhouse construction.

Since fish metabolic activities are directly influenced by environmental temperature, greenhouse systems must be regularly monitored to prevent extreme heating or cooling, which could negatively impact fish performance. Additionally, greenhouse systems play a dual role in mitigating extreme weather conditions: they help control excessive evaporation rates during hot seasons and maintain stable temperatures during extremely cold seasons (Omorodion and Madu, 2013).

Water temperature is the primary environmental factor influencing the growth and development of aquatic organisms. To sustain aquaculture production year-round, water temperature must be maintained within physiologically acceptable ranges. A common approach to achieving this is placing production units within enclosed structures where air and water are less affected by external climatic conditions. Greenhouse structures, which are typically used for vegetable and flower production, serve as cost-effective solutions for indoor aquaculture, as they are generally inexpensive to construct (Li et al., 2009).

The results show that construction of greenhouses in guadua for ponds using *Guadua angustifolia*, is an economical choice for fish farmers; the plastic covers of the ponds allow adequate control of the temperature of the water in the ponds and controls 100% fish predation by piscivorous birds. It is concluded that ground-floor ponds and plastic cover were the more efficient presenting ease of use, increased production of plankton, better productive and economical yield, coinciding with a greater thermal stability, followed by the ground-floor ponds without plastic cover, making it a viable alternative to optimize fish production. (Hahn-Von-Hessberg and Grajales-Quintero, 2016).

Maintaining optimal water temperature is essential for the growth, reproduction, and disease control of aquatic animals. One of the key advantages of greenhouse systems in aquaculture is their ability to reduce environmental variability. In regions where installation and heating costs are economically feasible, greenhouse-based aquaculture presents a highly advantageous production method (Öz, 2012).

This research was carried out to determine the effects of in-greenhouse and outdoor greenhouse ponds used in aquaculture on water temperature changes, and the determined water temperature values were evaluated in terms of ornamental aquaculture.

2. Materials and Methods

The research was carried out in a production facility with in-greenhouse and out-greenhouse ponds for aquaculture of edible and ornamental fish in Antalya province between February-April 2016 for 48 days in the cold period.

The study aimed to determine the differences in water temperature between fish ponds located outside and those inside a polyethylene-covered greenhouse. No heating system was utilized inside the greenhouse. The water depth in the ponds was 80 cm. The greenhouse had a length of 3 meters and a height of 1 meter. Daily measurements were conducted, recording the air temperature inside the greenhouse as well as the water temperature in both the greenhouse and outdoor ponds in the morning, noon, and evening (Li et al., 2009;

Omorodion and Madu, 2013).

2.1. Statistical Analyses

Statistical analyses were performed using Minitab Release 17 for Windows at a 5% level of significance. Data are presented as mean ± standard error (SE). The normality of the data obtained from different groups was investigated and ANOVA was used since the distribution was normal. One-way analysis of variance (ANOVA) was applied to analyze data from different experimental groups for each sampling period, followed by Tukey's HSD post hoc test for multiple comparisons, with significance set at $p < 0.05$.

3. Results and Discussion

In the Antalya region, over 48 days between February and April, the average water temperature in the greenhouse and outdoor ponds was determined to be 23.53±0.16 °C and 15.37±0.16 °C, respectively, while the average air temperature inside the greenhouse was recorded as 28.15±0.56 °C. Statistical analysis indicated that the difference between the average water temperatures was significant ($p<0.05$).

The minimum and maximum water temperatures recorded in the greenhouse ponds were 19°C and 27°C, while in the outdoor ponds, these values were 10°C and 19°C, respectively. The temperature difference between indoor and outdoor ponds was approximately 8.2 °C. Moreover, the average water temperature values recorded at morning, noon, evening, and night are presented in Table 1 and Figure 1.

Table 1. Average water temperature values (°C) recorded at different times of the day

Water Temperature (°C)	Morning	Noon	Evening	Night	Overall Average
Indoor Greenhouse Pond	22.57±0.20	24.37±0.29	24.08±0.29	22.53±0.40	23.53±0.16[a]
Outdoor Greenhouse Pond	14.62±0.25	16.22±0.25	15.81±0.31	14.55±0.44	15.37±0.16[b]

Different superscripts ([a], [b]) indicate a statistically significant difference between indoor and outdoor pond temperatures ($p<0.05$).

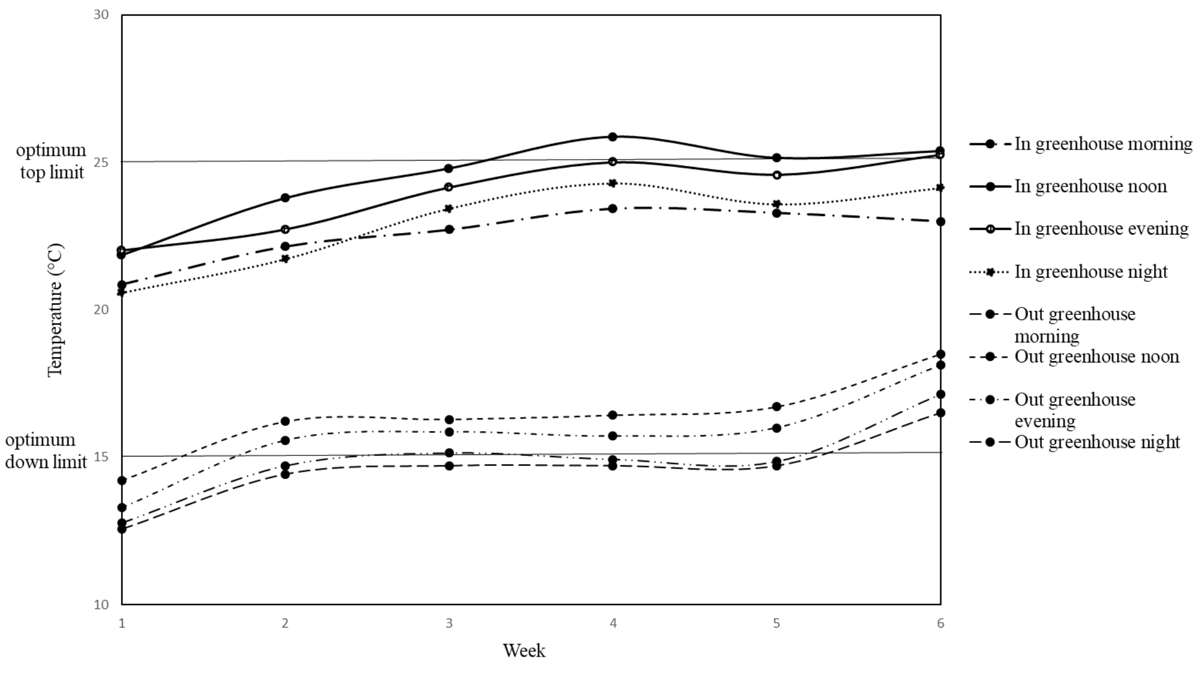


Figure 1. Average water temperature values (°C) recorded at weekly

The finding of this study, which indicates that the water temperature inside the greenhouse is higher than that outside, is consistent with the results of previous research (Omorodion and Madu, 2013; Josiah et al., 2014; Akidiva et al., 2020; Emam et al., 2023; Yongphet et al., 2016) (Table 2).

Table 2. Water temperature values in fish ponds inside and outside the greenhouse in different research and this research

Research	Inside greenhouse (°C)	Outside greenhouse (°C)	Temperature difference (°C)
Li et. al., 2009	min. 16-max. 18	min.6-max. 8	10
Akidiva et al., 2020	23.56	18.72	4.84
Omorodion and Madu, 2013	31-41	25-38	6-3
Yongphet, et al., 2016	26.7	26.4	0.3
Emam et al., 2023	28.06	26.12	1.94
Josiah et al., 2014	24.2	20.5	3.7
This research	23.53	15.37	8.16

Previous studies have also determined that temperature values inside the greenhouse are higher than those outside. This phenomenon is attributed to the greenhouse's ability to trap solar radiation, retain heat, and maintain temperature stability. Therefore, the proper management of temperature and humidity within the greenhouse is a critical factor for the success of greenhouse-based systems. In a study that monitored air temperature, water temperature, and evaporation readings over two weeks, the recorded temperatures inside the greenhouse were found to be 25–27 °C at 6:00 and 26–32 °C at 18:00, whereas the corresponding temperatures outside the greenhouse were 22–25 °C at 6:00 and 24–28 °C at 18:00 (Omorodion and Madu, 2013).

In aquaculture, the recommended optimal water temperature range for the production of many species is between 21–29 °C (Li et al., 2009). It has been reported that lower temperatures outside this range are not suitable for the optimal growth of warm-water fish species such as Nile tilapia. In such environments, greenhouse systems are among the technologies used in aquaculture to regulate water temperature and ambient humidity, as well as to prevent sudden drops or increases in temperature. There was a significant difference in the mean daily temperature recorded in the two pond systems. Greenhouse recorded a mean daily temperature of 23.56±1.74 ˚C with a maximum temperature of 27.13 ˚C and minimum of 20.90 ˚C while the open pond had mean temperature of 18.72±2.09 ˚C with maximum temperature of 24.40 ˚C and minimum of 15.60 ˚C recorded (Akidiva et al., 2020).

Akidiva et al. (2020) reported that the greenhouse pond temperature was within the recommended range of 22-28°C, which is suitable for Nile tilapia, and that the higher average temperature recorded in the greenhouse pond, as opposed to the open pond, was due to the “greenhouse effect”. During sunlight exposure, the total solar radiation received by the greenhouse cover is partially reflected, absorbed, and transmitted into the greenhouse through the walls and roof. A significant portion of this transmitted radiation is absorbed by the water, leading to an increase in temperature. In the greenhouse pond, Nile tilapia exhibited a specific growth rate (SGR) mean value of 1.15±0.01 compared to 0.82±0.01 in the open pond.

According to Yongphet et al. (2016), generally, farmers must grow fish until they reach marketable size within approximately 6-8 months. However, in climbing perch (*Anabas testudineus*) aquaculture, controlling the water temperature between 28-32°C during winter and rainy seasons can shorten the required culture period to approximately 3-4 months. This approach can reduce production costs and save time. The average water temperature was determined as 26.4 °C during the day and 26.2 °C at night in the non-greenhouse fish cage, 26.7 °C during the day and 26.4 °C at night in the greenhouse fish cage, and 27.6 °C during the day and 26.5 °C at night in the fish cage integrated with a greenhouse heat loss reduction system. These results support the use of plastic film covering ponds, promoting higher growth performance and lower production costs. This study confirmed that the greenhouse system could be a promising method for climbing perch (*Anabas testudineus*) farming during cold seasons. The experimental results suggest that an insulated fish cage integrated with a greenhouse and a warm air ventilator could be beneficial for achieving higher fish growth rates and advantageous for fish farmers.

Zhu et al. (1998) indicated that simulation results showed that in a 1-meter-deep small lake, passive polyethylene greenhouse small lake systems could achieve a 5.2 °C increase in water temperature compared to the external air temperature. Water temperature values were recorded as 28.06±2.34 °C in the greenhouse and 26.12±2.91 °C in the control. Dissolved oxygen concentrations were also significantly higher in greenhouse small lakes compared to control ponds, recorded as 13.02±2.12 mg/L in the was reported between greenhouse and 11.38±1.36 mg/L in the control. However, no significant difference greenhouse and control ponds in terms of pH or total ammonia nitrogen (Emam et al., 2023).

According to Josiah et al. (2014), water temperatures in Kenya's high-altitude regions range between 16.5 °C and 22.5 °C, which is significantly lower than the optimal range of 24 °C to 32 °C known to be suitable for most tropical freshwater fish. Maintaining the required temperature for optimal metabolic range remains a challenge for many small-scale rural farmers. Greenhouses have been found effective in regulating temperatures within the required range with minimal fluctuations. Some studies have demonstrated that water temperature in a greenhouse can be increased by 3-9 °C (Zhu et al., 1998; Ghosal et al., 2005). The greenhouse treatment showed an average increase of 3.67 °C in water temperature compared to the outside treatment. Given that the growth of *Clarias gariepinus* in Kenya's high-altitude regions is largely constrained by low temperatures, adopting this technology could help achieve better growth and production in these areas. Greenhouses provide a relatively inexpensive supplementary heating technology to raise water temperature, thereby enhancing fish growth. Such a simple technology offers an additional advantage in cost reduction, ultimately increasing the profits of small-scale rural fish farmers. Consequently, the present study demonstrated that greenhouse use significantly increased internal greenhouse temperatures and enhanced the growth of African catfish juveniles. Stocking density and greenhouse-reared juveniles influenced fish growth performance, resulting in higher growth rates in terms of SGR, mean length, and weight gain. Greenhouse cultivation also improved the survival rate of *C. gariepinus* juveniles, as the recorded survival percentage inside the greenhouse was higher than outside.

Das et al. (2010) showed that water temperature increases of 4.13-6.92 °C could be achieved in greenhouse ponds with two collectors, while increases of 3.12-5.64 °C could be achieved in greenhouse ponds without collectors. Fish production in greenhouses was also significantly higher than in open ponds. In the study, *Cyprinus carpio* juveniles initially weighing 13.5 g reached weights of 53.8 g inside the greenhouse and 27.9 g outside, with the difference being statistically significant.

Ghosh et al. (2008) reported that the amount of fish produced in greenhouse and open ponds was 1.273 kg and 0.636 kg, respectively, while water temperature ranged from 18.5-21.5 °C in greenhouses and 13.0-15.5 °C in open ponds.

A model by Klemetson and Rogers (1985) describes the heat balance of open ponds by taking into consideration evaporation, convection and thermal radiation from the pond surface and the solar radiation absorbed by the water. The effects of greenhouses on the heat balance of ponds were modeled by assuming the air surrounding the ponds is saturated and wind speed is zero. The simulation study of Klemetson and Rogers (1985) predicted rise of water temperature by 2.8–4.4 °C. Little and Wheaton (1987) suggest using a computer model that a water temperature rise of 9–10 °C is achievable by placing a greenhouse cover. The experiment by Gaigher and Leu (1985) shows the water temperature of a pond using solar heating was about 6 °C above open pond water temperature (Li et al., 2009).

The numerical differences in findings obtained in research on this subject are believed to be the natural result of variations in environmental conditions such as seasonal characteristics specific to regions, water depth, pond location, and the structural material of the greenhouse and greenhouse cover. When evaluating the overall results, previous studies have indicated that water temperature differences between greenhouse and non-greenhouse ponds could increase by approximately 10°C during cold seasons, while in this study, an increase of up to 8°C was observed.

4. Conclusion

Based on the data obtained from this study, it has been determined that in regions with temperate climates where aquaculture is practiced, greenhouse systems significantly contribute to maintaining water temperature values during the winter season. This ensures the uninterrupted and targeted production of tropical and temperate aquatic species throughout the year. Many freshwater aquarium fish require water temperatures of 23 °C to 28 °C. For instance, species of the Poecilidae family, such as guppy, swordtail, molly, and platy, as well as species of the Cichlidae family, such as angelfish, discus, ahli, and demasoni, and labyrinth fish species like betta, gourami, and paradise fish, are classified as tropical species. Additionally, species such as goldfish and koi, known as warm-water species, have ideal water temperature ranges of 15-25 °C. In Türkiye, a significant portion of aquarium fish trade involves imported species. Although aquarium fish farming is developing domestically, production remains limited in meeting demand. Antalya and its surroundings provide favorable conditions for aquarium fish farming and are among the leading regions for this activity. The results of this study indicate that while the average outdoor pond water temperature was around 15 °C, the greenhouse pond water temperature was approximately 23.5 °C during the 48-day period between February and April in the Antalya region. These findings support the conclusion that greenhouse systems are a crucial production practice for aquaculture, particularly for tropical aquarium fish species.

5. Acknowledgements

I would like to thank İsmail DAL for his support in collecting this research data.

6. Compliance with Ethical Standards

a) Authors' Contributions

Ü. Ö.: designed, performed the experiment and data analysis, data collection and wrote the work.

b) Conflict of Interest

The authors declare that there is no conflict of interest.

c) Statement on the Welfare of Animals

Ethics committee approval is not necessary for this study.

d) Statement of Human Rights

This study does not involve human participants.

e) Funding

This study was not supported by any founder.

7. References

Akidiva, A. A., Yasindi, A. W. & Kitaka N. (2020). Influence of greenhouse technology on selected pond water quality parameters and growth performance of Nile tilapia in high altitude areas. International Journal of Fisheries and Aquatic Studies, 8(4): 142-147.

Das, T., Tiwari, G.N. & Sarkar, B. (2010). Thermal performance of a greenhouse fish pond integrated with flat plate collector. International Journal of Agricultural Research, 1(5): 406-419. https://doi.org/10.3923/ijar.2006.406.419

Emam, W., Bakr, M. E., Abdel-Kader, M. F., Abdel-Rahim, M. M., Elhetawy, A. I. G. & Mohamed, R. A. (2023). Modifying the design of pond production systems can improve the health and welfare of farmed Nile Tilapia, *Oreochromis niloticus*. Pakistan J. Zool., 1-6. https://dx.doi.org/10.17582/journal.pjz/20220926220926

Gaigher, I.G. & Leu, B.Y. (1985). Solar heating for wintering of tilapia. Sunworld 9 (2): 42–52.

Ghosal, M.K., Tiwari, G.N., Das, D.K. & Pandey, K.P. (2005). Modeling and comparative thermal performance of ground air collector and earth air heat exchanger for heating of greenhouse. Energy and Buildings, 37(6):613-621.

Ghosh, L., Tiwari, G.N., Das, T. & Sarkar, B. (2008). Modeling the thermal performance of solar heated fish pond: An experimental validation. Asian Journal of Scientific Research, 1(4): 338 350.

Hahn-Von-Hessberg, C.M. & Grajales-Quintero A., (2016). Evaluación de invernaderos en producciones piscícolas. Bol. Cient. Mus. Hist. Nat. U. de Caldas, 20 (2): 124-137. https://doi.org/10.17151/bccm.2016.20.2.9

Hamed, S.A., Abou-Elnaga, A., Salah, A.S., Abdel-Hay, A.H.M., Zayed, M.M., Soliman, T., Mohamed, R.A., 2021. Effect of water temperature, feeding frequency, and protein percent in the diet on water quality, growth and behavior of Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758). Journal of Applied Ichthyolology, 37: 462-473. https://doi.org/10.1111/ jai.14193

Harrahy, L.N., Schreck, C.B., and Maule, A.G., 2001. Antibody-producing cells correlated to body weight in juvenile chinook salmon (*Oncorhynchus tshawytscha*) acclimated to optimal and elevated temperatures. Fish Shellfish Immunol., 11: 653- 659. https://doi.org/10.1006/fsim.2001.0342

Josiah, A.S., Mwatete, M. C. & Njiru, J. (2014). Effects of greenhouse and stocking density on growth and survival of African Catfish (*Clarias gariepinus* Burchell 1822) fry reared in high altitude Kenya Regions. International Journal of Science and Research (IJSR), 3(9): 2319-7064.
Klemetson, S.L. & Rogers, G.L. (1985). Aquaculture pond temperature modeling. Aquacultural Engineering, 4: 191–208.
Li, S., Willits, D. H., Browdy, C. L., Timmons, M. B. & Losordo, T. M. (2009). Thermal modeling of greenhouse aquaculture raceway systems. Aquacultural Engineering 41: 1–13. https://doi.org/10.1016/j.aquaeng.2009.04.002
Likongwe, J.S., Stecko, T.D., Stauffer, Jr, J.R., and Carline, R.F., 1996. Combined effects of water temperature and salinity on growth and feed utilization of juvenile Nile tilapia *Oreochromis niloticus* (Linneaus). Aquaculture, 146: 37-46. https://doi.org/10.1016/S0044-8486(96)01360-9
Little, M.A. & Wheaton, F.W. (1987). Water temperature prediction in a greenhouse covered aquaculture pond: A Progress Report. ASAE Paper No. 87-4022. American Society of Agricultural Engineers, St. Joseph, MI, USA.
Mamun Siddiky, M.N.S. & Mondal, B. (2016). Breeding technique of goldfish, molly, guppy and its impact on economy in the rural area of the Purba Midnapore district, West Bengal, India. International Journal of Advanced Multidisciplinary Research (IJAMR), 3(8):34-40.
Mashaii, N., Rajabipour F., Hosseinzadeh H. & Hafezieh, M. (2021). Greenhouse tilapia culture in aquaponic system. Journal of Survey in Fisheries Sciences, 7(2): 209- 217.
Musal, S., Orina, P.S., Aura, C.M., Kundu, R., Ogello, E.O., and Munguti, J.M., 2012. The effects of dietary levels of protein and greenhouse on growth, behaviour and fecundity of Nile tilapia (*Oreochromis niloticus* L.) broodstock. Int. J. Sci. Res., 10: 2271-2278.
Omorodion, C. O. & Madu, E. (2013). Construction and application of greenhouse techniques for aquaculture practice in the arid zone of Nigeria. Proceedings of 28th Fison Annual Conference.
Öz, Ü. (2012). Su ürünleri yetiştiriciliğinde sera sisteminin kullanımı. Yunus Araştırma Bülteni, 3: 24-30.
Peng, J., Qiufen, D., Song, Z., Yong, Y., & Hinter, G. (2014). Shrimp farming in greenhouses: a profitable model to culture *Penaeus vannamei* in China. Internatonal AquFeed, January-February, 50-53.
Sarkar, B. & Tiwari, G.N. (2006). Thermal modeling and parametric studies of a greenhouse fishpond in the central Himalayan region. Energy Conversion and Management, 47: 3174–3184.
Sharma, S.K. (2021). Breeding of Livebearer Ornamental Fishes. Conference: Training programme on Ornamental Fish Farming for Self employment.
Sirimanna, S. R. & Chamari Dissanayake, C. (2019). Effects of culture conditions on growth and survival of *Poecilia sphenops* and *Poecilia reticulata*. Int. J. Aquat. Biol., 7(4): 202-210. https://doi.org/10.22034/ijab.v7i4.570
Srinivasan, M. (2013). A complete manual on ornamental fish culture. Edition: IPublisher: AV Akademikerverlag GmbH & Co. KG, GermanyEditor: Dr. MR. Rajan ISBN: 978-3-659-38095-2.
Tribeni, D., Tiwari, G., and Bikash, S., 2010. Thermal performance of a greenhouse fish pond integrated with flat plate collector. Int. J. agric. Res., 5: 851- 864. https://doi.org/10.3923/ijar.2010.851.864
Yongphet, P., Ramaraj, R. & Natthawud Dussadee, N. (2016). Effect of greenhouse cages integrated with using solar energy on the growth performance on freshwater fish. International Journal of New Technology and Research (IJNTR), 2 (3): 100-107.
Watson, C. A. & Shireman, J. V. (2002). Production of Ornamental Aquarium Fish 1 FA35, one of a series of the Fisheries and Aquatic Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.
Zhu, S., Deltour, J. & Wang, S. (1998). Modeling the thermal characteristics of greenhouse pond systems. Aqua cultural Engineering, 18: 201-217.

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

Kalsiyumun Ihlamur Odunlarında Birikimi ve Transferi

İnci Sevinç Kravkaz Kuşçu[1]*

Özet: Bitki beslenmesinde mutlak gerekli makro besin elementlerinden birisi olan kalsiyum (Ca) bitki büyümesi ve gelişiminde önemli bir yere sahiptir. Bundan dolayı özellikle uzun ömürlü ve büyük biyokütleye sahip ağaçların en büyük organı olan odun kısmında Ca birikiminin belirlenmesi önem taşımaktadır. Bu çalışmada orman, tarım ve peyzaj çalışmalarında önemli bir ağaç türü olan ıhlamur (*Tilia tomentosa*) gövde organlarında Ca'un organ, yön ve dönem bazında değişimi karşılaştırılmıştır. Çalışma kapsamında ana gövdenin farklı yönlerinden alınan dış kabuk, iç kabuk ve her yaş aralığındaki odunlarda Ca konsantrasyonu ICP-OES cihazı yardımıyla belirlenmiştir. Çalışma sonuçları kabuklardaki Ca konsantrasyonlarının daha yüksek seviyede olduğunu, ancak hem odunlarda hem de kabuklardaki Ca konsantrasyonlarının genel olarak dar bir aralıkta değişim gösterdiğini ortaya koymaktadır. Genel olarak değerlendirildiğinde *Tilia tomentosa*'nın Ca kirliliğinin değişiminin izlenmesi amacıyla kullanılabilecek uygun bir biyomonitor olmadığı, diğer birçok türe göre odunlarında daha düşük seviyede Ca biriktirebildiği söylenebilir. Bundan dolayı toprakta Ca eksikliği olan bölgelerde tercih edilmesi önerilmektedir.

Anahtar Kelimeler: Ihlamur, *Tilia tomentosa*, Kalsiyum, Biyomonitor, Fitoremediasyon

Accumulation and Transfer of Calcium in Linden Wood

Abstract: Calcium (Ca), one of the essential macronutrients in plant nutrition, has an important place in plant growth and development. Therefore, it is important to determine Ca accumulation in the wood part, which is the largest organ of trees with long life and large biomass. In this study, the changes in Ca in the trunk organs of linden (*Tilia tomentosa*), an important tree species in forest, agriculture and landscaping studies, were compared based on organ, direction and period. Within the scope of the study, the Ca concentration in the outer bark, inner bark, and wood of all age ranges taken from different parts of the main trunk was determined using an ICP-OES device. The study results show that Ca concentrations in the bark are higher, but Ca concentrations in both wood and bark generally change within a narrow range. When evaluated in general, it can be said that *Tilia tomentosa* is not a suitable biomonitor that can be used to monitor the change in Ca pollution, and that it can accumulate Ca at lower levels in its wood compared to many other species. Therefore, it is recommended to be preferred in regions with Ca deficiency in the soil.

Keywords: Linden, *Tilia tomentosa*, Calcium, Biomonitor, Phytoremediation

Makale Bilgisi (Araştırma)

1 Kastamonu Üniversitesi, Orman Fakültesi, Orman Mühendisliği Bölümü, Toprak İlmi ve Ekolojisi Anabilim Dalı, Kastamonu/Türkiye.
***Sorumlu yazar:**
ikravkaz@kastamonu.edu.tr

Alıntı: Kuşçu, İ.S.K., (2025). Kalsiyumun Ihlamur Odunlarında Birikimi ve Transferi, Memba Su Bilimleri Dergisi. 11, (2) 242-248. https://doi.org/10.58626/memba.1684785

Başvuru Tarihi: 27 Nisan 2025
Kabul Tarihi: 19 Haziran 2025
Yayın Tarihi: 28 Haziran 2025

1. Giriş

Bitkiler besin piramidinin temelini oluşturan canlılardır. Yetiştirildikleri ortamlarda güneş ışığını kullanarak klorofil yardımıyla fotosentez yapmakta ve diğer canlılar için gerekli olan besini üretmektedirler. Bundan dolayı dünyadaki bütün canlı yaşamı bitkilere bağımlıdır (Yigit vd., 2021). Bitkilerin, canlı yaşamı için öneminden dolayı, gelişimlerini etkileyen ve şekillendiren faktörler konusunda çok sayıda çalışma yapılmaktadır. Yapılan çalışmalar ortaya koymaktadır ki bitki gelişimi genetik yapı ile çevresel faktörlerin karşılıklı etkileşimi altında şekillenmektedir (Sevik vd., 2012; Kurz vd., 2023; Hrivnak vd., 2024; Ozturk Pulatoglu vd., 2025). Çevresel faktörler içerisinde en önemlileri de klimatik (Yigit vd., 2019; Aricak vd., 2024; Cantürk vd., 2024) ve edafik (Kravkaz Kuscu vd., 2018; Cobanoglu vd., 2023) faktörlerdir. Bu faktörler içerisinde besin elementleri bitki gelişimini en fazla etkileyen edafik faktörlerdendir (Erdem, 2022; Tandogan vd., 2023).

Bitki beslenmesinde 16 adet mutlak besin elementinden birisi olan kalsiyum (Ca) hücrelerin büyüme ve gelişiminde, membran geçirgenliklerinin ayarlanmasında, dokuların stablizasyonunda ve bitkilerin kalitesinde önemli role sahiptir. Ayrıca, toprağın fiziksel ve kimyasal özellikleri üzerine önemli etkileri bulunmaktadır. Bundan dolayı fauna, mikroflora, bitki ve toprak için vazgeçilmez öneme sahiptir. Ca noksanlığında bitkilerde verimin yanı sıra genellikle kalite düşmektedir (Erdem, 2022).

Ca, aynı zamanda önemli ve yaygın bir elementtir. Bazı elemetler, özellikle ağır metaller içerisinde bazıları düşük konsantrasyonlarda bile canlılar için toksik, kanserojen ve zararlı iken bitki besin elementi olarak gerekli olanlar bile yüksek konsantrasyonlarda canlılar için zararlı olabilmektedirler (Kuzmina vd., 2023; Isinkaralar vd., 2025a; Koc vd., 2025a;). Üstelik ağır metallerin toprak, su ve havadaki konsantrasyonlarının insan faaliyetlerine bağlı olarak sürekli arttığı belirtilmektedir (İpek vd., 2024; Mutlu ve Aydın Uncumusaoglu, 2024; Şevik vd., 2024; Tokatli vd., 2024; Demir vd., 2024). Küresel ölçekte en önemli sorunlar olarak kentleşme ve küresel iklim değişikliği ile birlikte gösterilen çevre kirliliğinin, neredeyse bütün ekosistemleri etkileyeceği belirtilmektedir (Sulhan vd., 2023; Bayraktar vd., 2024; Şevik vd., 2024). Çevre kirliliği bileşenleri içerisinde canlılar için en zararlılarının da ağır metaller olmasından dolayı son yıllarda ağır metallerin hava, su, toprak ve bitkilerdeki konsantrasyonlarının izlenmesi konusunda çok sayıda çalışma yapılmıştır (Ghoma vd., 2023; Koc vd., 2025b; Gültekin vd., 2025).

Ağır metal kirliliğinin izlenmesi konusunda yapılan çalışmalarda toprak ve sudaki ağır metal konsantrasyonları doğrudan ölçülebilmektedir (Demir vd., 2021; Emin ve Mutlu, 2024; Ergül ve Kravkaz Kuşçu, 2024). Ancak havadaki ağır metal kirliliğinin doğrudan ölçülmesi zor ve pahalıdır. Bundan dolayı havadaki ağır metal kirliliğinin değişiminin izlenmesinde genellikle biyomonitorler kullanılmaktadır (Erdem vd., 2024; Yaşar İsmail vd., 2025). Özellikle ağır metallerin uzun süreç içerisindeki değişiminin belirlenmesinde ağaçların yıllık halkaları oldukça kullanışlıdır (Sevik vd., 2024; Isinkaralar vd., 2025b). Ağaçların yıllık halkalarındaki ağır metal konsantrasyonları ağır metal kirliliğinin azaltılması amacıyla yapılan fitoremediasyon çalışmaları açısından da önemlidir. Çünkü odun kısmı bitkilerin en büyük organıdır ve odun kısmında biriktirilen ağır metaller, her yıl toprağa dökülerek tekrar doğaya salınan yaprak ve meyvelerdeki ağır metallerin aksine onlarca, yüzlerce hatta bazen binlerce yıl ortamdan uzak tutulmaktadır (Key vd., 2023; Koc vd., 2024). Bu durum aynı zamanda bitki besin elementleri için de bir dezavantaj sunmaktadır. Çünkü yaprak ve meyve gibi organlarda biriktirilen bitki besin elementleri birkaç yıl gibi kısa aralıklarla toprağa dökülüp ayrışarak bitki tarafından tekrar kullanılabilmektedir. Oysa odun kısmında biriktirilen besin elementleri çok uzun yıllar ortamdan uzak tutulduğundan toprağın besin elementlerince fakirleşmesi sonucunu doğurmaktadır. Bundan dolayı özellikle uzun ömürlü ve büyük kütleli ağaçların odun kısmında biriktirilen besin elementlerinin belirlenmesi önem taşımaktadır. Bu çalışmada da hem orman, hem ziraat hem de peyzaj çalışmalarında büyük önem taşıyan ıhlamur (*Tilia tomentosa*) ağaçlarında Ca'un bitki ana gövdesindeki odun ve kabuklardaki birikimi ve organlar arasındaki taşınımı (transferi) incelenmiştir.

2. Materyal ve Yöntem

Çalışma ülkemizde ve Avrupa genelinde hem orman hem de ziraat çalışmalarında önem taşıyan ayrıca peyzaj çalışmalarında sıklıkla kullanılan ıhlamur türlerinden *Tilia tomentosa* üzerinde gerçekleştirilmiştir. Çalışmaya konu ağaç Dünya Hava Kirliliği Raporu 2021'e göre Avrupa'nın havası en kirli 5 şehrinden birisi olan Düzce ilinden temin edilmiştir. (Koc vd., 2024). Numuneler, 2022 yılında vejetasyon sonunda kuzey yönü belirlenerek ana gövdeden yerden yaklaşık 50 cm yukarıdan kesilmek suretiyle alınmıştır. Laboratuvara getirilerek yüzeyi temizlenen kütük örneğinin 60 yaşında olduğu belirlenmiş, beşer yıllık olarak gruplandırılan odun kısmı ile iç kabuk ve dış kabuktan çelik matkap yardımıyla numuneler alınmıştır. Konu ile ilgili yapılan çalışmalarda yıllık halkaların tek tek analiz edilmesi genellikle mümkün olmadığından gruplandırma yapılmakta, grup sayısı; çalışma amacı, ağacın yıllık halka sayısı ve yıllık halkaların genişliği gibi kriterlere göre 3, 5 veya 10 yıllık olabilmektedir (Key vd., 2023; Canturk vd., 2024; Isinkaralar vd., 2024).

Alınan numuneler öncelikle oda kurusu hale gelmeleri için, havalandırılan bir odada, kartonlar üzerinde iki hafta bekletilmiş, daha sonra cam petri kaplarına alınarak 2 hafta, 3-4 günde bir cam bagetlerle karıştırılarak

45 °C etüvde kurutulmuştur. Kurutma işlemi sonunda, özel olarak tasarlanan mikrodalga fırında ön yakma işlemi uygulanmıştır. Numunelerde Ca analizi ICP-OES cihazı ile yapılmıştır. Çalışmada kullanılan yöntem, konu ile ilgili çalışmalarda son yıllarda yaygın olarak kullanılmaktadır (Sulhan vd., 2023; Ghoma vd., 2023).

Elde edilen veriler SPSS 22.0 paket programı kullanılarak analiz edilmiş ve verilere varyans analizi uygulanmıştır. Ayrıca minimum %95 güven düzeyinde ($p < 0,05$) istatistiksel olarak anlamlı farklılıklar gösteren faktörler için Duncan testi uygulanmıştır. Duncan testi sonuçları dikkate alınarak veriler tablo halinde sunulduktan sonra analizler ve yorumlamalar yapılmıştır.

3. Bulgular

Ihlamurda Ca konsantrasyonunun organ ve yön bazında değişimine ilişkin ortalama değerler ve istatistiki analiz sonuçları Tablo 1'de verilmiştir.

Tablo 1. Ihlamurda Ca konsantrasyonunun organ ve yön bazında değişimi

Organ	**Kuzey**	**Doğu**	**Güney**	**Batı**	**F Değeri**	Ortalama
Dış Kabuk	4948,8 bA	4953,4 bC	4948,4 bA	4950,8 bB	86,1***	4950,3 bB
İç Kabuk	4936,8 bC	4939,6 bD	4924,8 bA	4932,1 bB	126,9***	4933,3 bB
Odun	1611,7	1538,2	1704,0	1591,2	0,9 ns	1611,3 aA
F Değeri	82,1***	455,3***	337,0***	296,7***		743,1***
Ortalama	2087,5	2025,1	2165,8	2069,8	0,0 ns	

* $p < 0,05$; ** $p<0,01$; *** $p<0,001$; ns $p>0,05$. Küçük harfler dikey, büyük harfler yatay değerlerin yer aldığı Duncan testi gruplarını göstermektedir.

Tablodaki değerlere bakıldığında ıhlamurda Ca konsantrasyonu değişiminin tüm yönlerde organ bazında istatistiki olarak anlamlı düzeyde olduğu görülmektedir. Duncan testi sonuçlarına göre bütün yönlerde iki grup oluşmuş, odun ilk grupta kabuklar ikinci grupta yer almıştır. İç ve dış kabuklarda elde edilen değerlerin birbirine çok yakın olması dikkat çekmektedir. Ayrıca kabuklardaki Ca konsantrasyonu ile odunlardaki Ca konsantrasyonu arasında büyük oranda fark olduğu görülmektedir. Yön bazında ise odunda yönler arasında istatistiki olarak anlamlı düzeyde fark olmadığı görülmektedir. Kabuklarda ise yönler arasında istatistiki olarak anlamlı düzeyde fark bulunsa da elde edilen değerler birbirine çok yakın seviyededir. Ihlamurda Ca konsantrasyonunun dönem ve yön bazında değişimi Tablo 2'de verilmiştir.

Tablo 2. Ihlamurda Ca konsantrasyonunun dönem ve yön bazında değişimi

Yaş	**Kuzey**	**Doğu**	**Güney**	**Batı**	**F Değeri**	**Ortalama**
2018-2022	3404,7 iD	1205,3 aB	1736,4 dC	997,1 aA	7475,8***	1835,9 de
2013-2017	1094,2 aA	1533,1 fC	2082,0 eD	994,7 aA	4932,5***	1426,0 abc
2008-2012	1079,3 aA	1341,8 cC	1748,1 dD	1217,9 bB	1062,1***	1346,8 ab
2003-2007	1186,9 bA	1241,8 bB	1338,0 aC	1324,6 bcC	55,2***	1272,8 a
1998-2002	1273,0 cA	1327,6 cB	1349,6 aC	1485,8 cD	208,9***	1359,0 ab
1993-1997	1353,8 dA	1464,4 dB	1352,0 aA	1620,4 dC	317,1***	1447,7 abc
1988-1992	1351,3 dA	1494,6 eB	1640,3 cC	1726,9 eD	290,8***	1553,2 abcd
1983-1987	1586,2 fAB	1573,5 gA	1612,6 bB	1664,7 deC	18,7**	1609,2 bcde
1978-1982	1574,5 efA	1705,3 hC	1621,6 bcB	2028,3 fD	730,7***	1732,4 cde
1973-1977	1552,5 eA	1529,9 fA	1608,4 bB	1813,4 efC	177,7***	1626,0 bcde
1968-1972	1725,8 gA	1837,3 iB	2070,0 eC	1855,5 efB	181,4***	1872,1 e
1963-1967	2157,9 hA	2204,2 jB	2289,5 fC	2365,5 gD	73,7***	2254,3 f
F	4135,8***	1139,9***	1225,7***	1076,8***		8,2***
Odun	1611,7	1538,2	1704,0	1591,2	0,9 ns	

** $p<0,01$; *** $p<0,001$; ns $p>0,05$. Küçük harfler dikey, büyük harfler yatay değerlerin yer aldığı Duncan testi gruplarını göstermektedir.

Varyans analizi sonuçlarına göre ıhlamurda Ca konsantrasyonu değişiminin tüm dönemlerde yön bazında ve tüm yönlerde dönem bazında istatistiki olarak anlamlı düzeyde ($p<0,001$) olduğu belirlenmiştir. Ortalama değerlere bakıldığında yön bazında dikkat çeken bir değişiklik olmadığı görülmektedir. Dönem bazında ise ortalama değerlere göre son dönem dışında genel olarak odun yaşı ile doğrusal olarak bir artış olduğu görülmektedir. Bunun dışında dikkat çeken bir diğer husus en düşük ve en yüksek değerler arasındaki farkın oldukça az olmasıdır. En düşük değer (batı yönde, 2013-2017 döneminde elde edilen 994,7 ppm) ile en yüksek değer (kuzey yönde, 2018-2022 döneminde elde edilen 3404,7 ppm) arasında 3,5 kattan az bir fark olduğu ve elde edilen değerlerin çoğunun 1000-2000 ppm arasında değişim gösterdiği görülmektedir.

4. Sonuç ve Tartışma

Çalışma sonucunda ıhlamur ağacının kabuklarında (hem iç kabuk, hem de dış kabuk) belirlenen Ca konsantrasyonunun odundakine oranla çok yüksek düzeyde olduğu belirlenmiştir. Benzer sonuçlar başka ağaç türlerinde de elde edilmiştir. Erdem (2022) bazı orman ağaçları üzerinde yaptığı çalışmada, çalışmaya konu bütün türlerde odunda elde edilen konsantrasyonların kabuklardakinden çok daha düşük seviyede olduğunu belirlemiştir. Erdem (2022) çalışmasında Ca konsantrasyonunun odunlarda *Abies nordmanniana*'da 1614,8 ppm, *Pinus sylvestris*'de 1547,1 ppm ve *Fagus orientalis*'de 3907,9 ppm seviyesinde iken kabuklarda *Abies nordmanniana*'da 5901,4 ppm, *Pinus sylvestris*'de 8047,9 ppm ve *Fagus orientalis*'de 4999,7 ppm seviyesinde olduğunu belirlemiştir. Başka bir çalışmada Ca konsantrasyonunun odunlarda *Robinia pseudoacacia*'da 2790,4 ppm, *Cupressus arizonica*'da 1257,4 ppm ve *Platanus orientalis*'de 3753,6 ppm seviyesinde iken dış kabuklarda *Robinia pseudoacacia*'da 5636,2 ppm, *Cupressus arizonica*'da 5698,8 ppm ve *Platanus orientalis*'de 8105,7 ppm seviyesinde, iç kabuklarda ise *Robinia pseudoacacia*'da 8105,6 ppm, *Cupressus arizonica*'da 8025,7 ppm ve *Platanus orientalis*'de 8097,5 ppm seviyesinde olduğu belirlenmiştir (Işınkaralar ve Erdem, 2021). Yapılan çok sayıda çalışmada da özellikle dış kabuktaki ağır metal konsantrasyonlarının odundakinden daha yüksek seviyede olduğu belirlenmiştir.

Çalışma sonucunda odun dokularında Ca konsantrasyonunun dar bir aralıkta değişim gösterdiği, komşu odun dokularında belirlenen Ca konsantrasyonlarının birbirine oldukça yakın olduğu belirlenmiştir. Bu durum Ca'un odun dokuları arasında taşınım olabileceğini göstermektedir . Bilindiği üzere havadaki ağır metal konsantrasyonlarının değişiminin izlenmesinde kullanılabilecek ağaç türlerinde, ağır metalin odun dokusu içerisinde taşınımının sınırlı olması, aranan bir özelliktir. Bu güne kadar yapılan çalışmalarda her ağaç türünün farklı ağır metallerin biyomonitoru olarak uygun olabildiğini göstermektedir ve pek çok elementin farklı ağaç türlerinin odum dokuları arasında taşınım olabildiği belirlenmiştir. Örneğin Pb ve Zn'nin *Cedrus deodora*, As, Sr, Pd, V, Ag, Se, Sb ve Tl'nin *Pinus nigra*, Co'nun *Cedrus atlantica*, Bi, Li ve Cr'nin *Cupressus arizonica* odunları içerisinde taşınım olabildiği belirlenmiştir (Zhang, 2019; Şevik vd., 2024; Koç, 2025).

Ağır metal birikimi türlere ve aynı türdeki organlara göre önemli ölçüde değişiklik gösterebilmektedir (Koç vd., 2024). Bunun nedeni, bitkilerde ağır metallerin alımı ve birikiminde birçok faktörün eş zamanlı olarak rol oynamasıdır. Ağır metallerin bitki bünyesine girişi ve hareketi, bitki türü, organ yapısı, yüzey alanı, ağır metaller ile bitkiler arasındaki etkileşimler ve hava koşulları dahil olmak üzere çeşitli faktörlerden etkilenmektedir (Şevik vd., 2024; Koç, 2025; Kulaç vd., 2025). Ağır metaller bitki bünyesine topraktan kökler vasıtasıyla, havadan yapraklardaki stomalar vasıtasıyla veya gövde bölümlerinden doğrudan girebilmektedirler (Cobanoglu vd., 2023; Ozturk Pulatoglu vd., 2025). Ancak bu yolaklar arasında pek çok element için en fazla kullanılan yolak köklerdir. Bitkiler yetiştikleri topraklarda, gelişimleri için gerekli besin elementlerini kökleri vasıtasıyla topraktan alarak kullanmaktadırlar. Bunun sonucunda topraktaki besin elementi miktarı azalmakta ve bu durum bitki gelişimini etkilemektedir (Erdem, 2022). Çünkü bitki gelişimi çevresel faktörlerin etkisi altında şekillenmektedir (Aydın vd., 2018; Almansouri vd., 2020; Ertürk vd., 2024). Bitki gelişimini etkileyen temel faktörler özellikle klimatik ve edafik faktörler olmakla birlikte (Çobanoğlu vd., 2023; Özdikmenli vd., 2024; Şen vd., 2024 Hmeer ve Şevik, 2025), yapılan çalışmalar mikroklimatik ve mikroedafik faktörlerin bitki gelişimini ve bitki fenotipik özelliklerini makro faktörlerden daha fazla etkilediğini göstermektedir (Sevik vd., 2017; Yigit vd., 2021). Çünkü bitkiler, sıcaklık, su açığı, don, hastalık ve zararlılar, hava kirliliği, uygun olmayan klimatik ve edafik faktörler gibi birçok faktörden etkilenerek strese girebilmekte ve bu durumda bitki gelişimi ve fenotipik karakterleri büyük oranda etkilenmektedir (Sevik ve Topacoglu, 2015; Özel vd., 2024). Bu faktörler arasında bitki gelişimini en fazla etkileyen faktörlerden birisi de toprak bileşenleri yani topraktaki besin elementi miktarıdır ve bütün bu faktörler birbirlerini karşılıklı olarak etkilemektedir (Erdem, 2022; Ergül ve Kravkaz Kuşçu, 2024).

5. Öneriler

Çalışma kapsamında Ca'un *Tilia tomentosa* kabuk ve odunlarındaki konsantrasyonları değerlendirilmiştir. Çalışma sonuçları kabuklardaki Ca konsantrasyonlarının daha yüksek seviyede olduğunu, ancak hem odunlarda hem de kabuklardaki Ca konsantrasyonlarının genel olarak dar bir aralıkta değişim gösterdiğini ortaya koymaktadır. Özellikle odunlardaki değişim aralığının bu kadar kısıtlı olması, odun dokuları arasında Ca'un taşınım olabildiği şeklinde yorumlanmıştır. Bu durum çalışmaya konu türün Ca kirliliğinin değişiminin izlenmesi amacıyla kullanılabilecek uygun bir biyomonitor olmadığını göstermektedir.

Çalışma sonucunda elde edilen değerler literatür bilgileri ile karşılaştırıldığında, çalışmaya konu türün, özellikle yapraklı türlere kıyasla diğer birçok türe göre odunlarında daha düşük seviyede Ca biriktirebildiğini göstermektedir. Bu sonuç Ca kirliliği olan yerlerde türün fitoremediasyon çalışmaları için uygun bir tür olmadığı şeklinde yorumlanabilir. Fakat aynı zamanda toprakta Ca eksikliği olan bölgelerde, diğer türlere göre daha düşük seviyede Ca biriktirdiğinden tercih edilmesi önerilmektedir.

6. Etik Standartlara Uygunluk

a) Yazar katkıları
İSKK: Kavramsallaştırma, süreç, yazılım, doğrulama, biçimsel analiz, araştırma, materyaller, ilk taslağın oluşturulması, incelemenin oluşturulması ve düzenleme.

b) Çıkar çatışması
Yazarlar çıkar çatışması olmadığını beyan ettiler.

c) Hayvanların refahına ilişkin beyan
Bu çalışma Deney Hayvanları Yerel Etik Kurul Çalışma protokolünü kapsamamaktadır.

d) İnsan Hakları Beyanı
Bu çalışmada insan denek bulunmamaktadır.

e) Finansman
Bu çalışma Kastamonu Üniversitesi tarafından desteklenmiştir.

8. Kaynakça

Almansouri, E. H., Aydin, M., & Sen, S. G. (2020). Determination of Soil, Litter Properties and Carbon Stock Capacities of Different Stand Types in Western Black Sea Region. 6(12). 51-63

Aricak, B., Canturk, U., Koc, I., Erdem, R., Sevik, H. (2024). Shifts That May Appear in Climate Classifications in Bursa Due to Global Climate Change, Forestist. 74: 129-137. Doi:10.5152/ forestist.2024.23074

Aydın, M., Güneş Şen, S., & Celik, S. (2018a). Throughfall, stemflow, and interception characteristics of coniferous forest ecosystems in the western black sea region of Turkey (Daday example). Environmental monitoring and assessment, 190, 1-10.

Aydın, M., Güneş Şen, S., & Mafrak, M. (2018b). Change of Soil Organic Carbon Content in Pure Black Pine Stand. VIII. International Symposium on Ecology and Environmental Problems. P.384

Bayraktar, O. Y., Özel, H. B., Benli, A., Yılmazoğlu, M. U., Türkel, İ., Dal, B. B., Şevik, H. & Kaplan, G. (2024). Sustainable foam concrete development: Enhancing durability and performance through pine cone powder and fly ash incorporation in alkali-activated geopolymers. Construction and Building Materials, 457, 139422.

Canturk, U., Koç, İ., Ozel, H. B., & Sevik, H. (2024). Identification of proper species that can be used to monitor and decrease airborne Sb pollution. Environmental Science and Pollution Research, 31(44), 56056-56066.

Cantürk, U., Koç, İ., Özel, H. B., & Şevik, H. (2024). Possible changes of Pinus nigra distribution regions in Türkiye with the impacts of global climate change. BioResources, 19(3), 6190- 6214. DOI:10.15376/biores.19.3.6190-6214

Cobanoglu, H., Sevik, H., & Koç, İ. (2023). Do annual rings really reveal Cd, Ni, and Zn pollution in the air related to traffic density? An example of the cedar tree. Water, Air, & Soil pollution, 234(2), 65.

Çobanoglu, H., Canturk, U., Koç, İ., Kulaç, Ş., & Sevik, H. (2023). Climate change effect on potential distribution of anatolian chestnut (*Castanea sativa* Mill.) in the Upcoming Century in Türkiye. Forestist, 73(3), 247-256. DOI: 10.5152/forestist.2023. 22065.

Demir, T., Mutlu, E., & Gültepe, N. (2024). Bioaccumulation of heavy metals in Capoeta tinca fish and health risk assessment. Revista Cientifica de la Facultade de Veterinaria, 34(2).

Demir, T., Mutlu, E., Aydın, S., & Gültepe, N. (2021). Physicochemical water quality of Karabel, Çaltı, and Tohma brooks and blood biochemical parameters of Barbus plebejus fish: assessment of heavy metal concentrations for potential health risks. Environmental Monitoring and Assessment, 193, 1-15.

Emin, N., & Mutlu, E. (2024). Akgöl Gölet Havzasının (Sinop-Ayancık) Su Kalitesinin Yerinde Analizlerle Tespiti ve Ağır Metal Kirliliğinin Araştırılması. Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi, 10(3), 243-252.

Erdem, R. (2022). Change of Calcium Concentrations in Forest Soils by Plant Species and Soil Depth. Kastamonu University Journal of Engineering and Sciences, 8(2), 122-127.

Erdem, R., Koç, İ., Çobanoğlu, H., & Şevik, H. (2024). Variation of magnesium, one of the macronutrients, in some trees based on organs and species. Forestist, 74(1), 84-93.

Ergül, H. A., & Kravkaz Kuşçu, İ. S. (2024). Variations in Sr, Tl, and V concentrations at copper mining sites based on soil depth, plant species, and plant organ. BioResources, 19(4), 793.

Ertürk, N., Arıcak, B., Yiğit, N., & Sevik, H. (2024). Potential changes in the suitable distribution areas of *Fagus orientalis* lipsky in kastamonu due to global climate change. Forestist, 74: 159-165. doi:10.5152/

forestist.2024.23024.
Ghoma, W. E. O., Sevik, H., & Isinkaralar, K. (2023). Comparison of the rate of certain trace metals accumulation in indoor plants for smoking and non-smoking areas. Environmental Science and Pollution Research, 1-9.
Gültekin, Y., Kılıç Bayraktar, M., Sevik, H., Cetin, M., Bayraktar, T. (2025) Optimal Vegetable Selection in Urban and Rural Areas Using Artificial Bee Colony Algorithm: Heavy Metal Assessment and Health Risk, Journal of Food Composition and Analysis, DOI: 10.1016/j.jfca.2024.107169.
Hmeer, A. I. A., & Şevik, H. (2025). Bazı Bitkilerin Farklı Organlarındaki Çinko Konsantrasyonlarına Trafik Yoğunluğunun Etkisi. Mehmet Akif Ersoy Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 16(1), 46-52.
Hrivnák, M., Krajmerová, D., Paule, L., Zhelev, P., Sevik, H., Ivanković, M., Goginashvili, N., Paule, J., Gömöry, D. (2024). Are there hybrid zones in *Fagus sylvatica* L. sensu lato?. Eur J Forest Res 143, 451–464. https://doi.org/10.1007/s10342-023-01634-0
Isinkaralar, K., Isinkaralar, O., Koç, İ., Özel, H. B., & Şevik, H. (2024). Assessing the possibility of airborne bismuth accumulation and spatial distribution in an urban area by tree bark: A case study in Düzce, Türkiye. Biomass conversion and biorefinery, 14(18), 22561-22572.
Isinkaralar, K., Isinkaralar, O., Koç, İ., Şevik, H., & Özel, H. B. (2025a). Atmospheric Trace Metal Exposure in a 60-Year-Old Wood: A Sustainable Methodological Approach to Measurement of Dry Deposition. International Journal of Environmental Research, 19(4), 1-14.
Isinkaralar, O., Isinkaralar, K., & Sevik, H. (2025b). Health for the future: spatiotemporal CA-MC modeling and spatial pattern prediction via dendrochronological approach for nickel and lead deposition. Air Quality, Atmosphere & Health, 1-13.
Işınkaralar, K., & Erdem, R. (2021). Changes of calcium content on some trees in Kocaeli. Kastamonu University Journal of Engineering and Sciences, 7(2), 148-154.
İpek, G. G., Aras, S., Arslan, N., & Mutlu, E. (2024). Evaluation of Freshwater Water Quality with Indexes and GIS-Based: A Case Study, Güren Stream (Küre Mountains National Park, Western Black Sea Basin, Turkey). Water Resources, 51(3), 332-343.
Key, K., Kulaç, Ş., Koç, İ., & Sevik, H. (2023). Proof of concept to characterize historical heavy-metal concentrations in atmosphere in North Turkey: determining the variations of Ni, Co, and Mn concentrations in 180-year-old *Corylus colurna* L. (Turkish hazelnut) annual rings. Acta Physiologiae Plantarum, 45(10), 120.
Koc, I., Cobanoglu, H., Canturk, U., Key, K., Kulac, S., & Sevik, H. (2024). Change of Cr concentration from past to present in areas with elevated air pollution. International Journal of Environmental Science and Technology, 21(2), 2059-2070.
Koc, I., Cobanoglu, H., Canturk, U., Key, K., Sevik, H., & Kulac, S. (2025a). Variation of 40-year Pb deposition in some conifers grown in the air-polluted-urban area of Düzce, Türkiye. Environmental Earth Sciences, 84(7), 186.
Koc, İ., Canturk, U., Cobanoglu, H., Kulac, S., Key, K., & Sevik, H. (2025b). Assessment of 40-year Al Deposition in some Exotic Conifer Species in the Urban Air of Düzce, Türkiye. Water Air Soil Pollut 236, 76. https://doi.org/10.1007/s11270-024-07723-z
Koç, İ. (2025). Chronological Levels of As, Pd, V, and Sr in 356-year-old *Pinus nigra* Annual Rings in Northern Türkiye. BioResources, 20(1). 2215-2233
Koç, İ., Canturk, U., Isinkaralar, K., Ozel, H. B., & Sevik, H. (2024). Assessment of metals (Ni, Ba) deposition in plant types and their organs at Mersin City, Türkiye. Environmental Monitoring and Assessment, 196(3), 282.
Kulac, S., Pulatoglu, A.O., Koç, İ., Sevik, H., & Ozel, H. B. (2025). Assessing Tree Species for Monitoring and Mitigating Strontium Pollution in Urban Environments. Water Air Soil Pollut 236, 605 (2025). https://doi.org/10.1007/s11270-025-08244-z
Kravkaz-Kuscu, I. S., Sariyildiz, T., Cetin, M., Yigit, N., Sevik, H., & Savaci, G. (2018). Evaluation of the soil properties and primary forest tree species in Taskopru (Kastamonu) district. Fresenius Environmental Bulletin, 27(3), 1613-1617.
Kurz, M., Koelz, A., Gorges, J., Carmona, B. P., Brang, P., Vitasse, Y., ... & Csillery, K. (2023). Tracing the origin of Oriental beech stands across Western Europe and reporting hybridization with European beech–Implications for assisted gene flow. Forest Ecology and Management, 531, 120801.
Kuzmina, N., Menshchikov, S., Mohnachev, P., Zavyalov, K., Petrova, I., Ozel, H. B., Aricak, B., Onat, S. M., & Sevik, H. (2023). Change of aluminum concentrations in specific plants by species, organ, washing, and traffic density, BioResources 18(1), 792-803.
Mutlu, E., & Aydın Uncumusaoglu, A. (2024). Research on Water Quality for Evaluation Using the Water Quality Index and Multivariate Statistical Approach of Evrenye Stream (Kastamonu, Türkiye). Polish Journal of Environmental Studies. https://doi.org/10.15244/pjoes/192355
Ozturk Pulatoglu, A., Koç, İsmail, Özel, H. B., Şevik, H., & Yıldız, Y. (2025). "Using trees to monitor airborne Cr pollution: Effects of compass direction and woody species on Cr uptake during phytoremediation,"

BioResources 20(1), 121–139.
Özdikmenli, G., Yiğit, N., Özel, H. B., & Şevik, H. (2024). Altitude-dependent Variations in Some Morphological and Anatomical Features of Anatolian Chestnut. BioResources, 19(3). 4635-4651
Özel, H. B., Şevik, H., Yıldız, Y., & Çobanoğlu, H. (2024). Effects of Silver Nanoparticles on Germination and Seedling Characteristics of Oriental Beech (*Fagus orientalis*) Seeds. BioResources, 19(2). 2135-2148.
Sevik, H., & Topacoglu, O. (2015). Variation and inheritance pattern in cone and seed characteristics of Scots pine (*Pinus sylvestris* L.) for evaluation of genetic diversity. Journal of Environmental Biology, 36(5), 1125.
Sevik, H., Cetin, M., Kapucu, O., Aricak, B., & Canturk, U. (2017). Effects of light on morphologic and stomatal characteristics of Turkish Fir needles (*Abies nordmanniana* subsp. *bornmulleriana* Mattf.). Fresenius Environmental Bulletin, 26(11), 6579-6587.
Sevik, H., Koç, İ., & Cobanoglu, H. (2024). Determination of some exotic landscape species as biomonitors that can be used for monitoring and reducing Pd pollution in the air. Water, Air, & Soil Pollution, 235(10), 615.
Sevik, H., Yahyaoglu, Z., & Turna, I. (2012). Determination of genetic variation between populations of *Abies nordmanniana* subsp. *bornmulleriana* Mattf according to some seed characteristics, genetic diversity in plants. Chapter, 12, 231-248.
Sulhan, O. F., Sevik, H., & Isinkaralar, K. (2023). Assessment of Cr and Zn deposition on *Picea pungens* Engelm. in urban air of Ankara, Türkiye. Environment, development and sustainability, 25(5), 4365-4384.
Şen, S. G., & Aydın, M. (2024). Farklı Meşcere Türlerinde Ormanaltı Yağış, Gövdeden Akış ve İntersepsiyonun Belirlenmesi. Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi, 10(1), 115-123.
Şevik, H., Yildiz, Y., Ozel, H.B. (2024). Phytoremediation and Long-term Metal Uptake Monitoring of Silver, Selenium, Antimony, and Thallium by Black Pine (*Pinus nigra* Arnold)", BioResources, 19(3). 4824-4837.
Tandogan, M., Özel, H. B., Gözet, F. T., & Şevik, H. (2023). Determining the taxol contents of yew tree populations in western Black Sea and Marmara regions and analyzing some forest stand characteristics, BioResources 18(2), 3496-3508.
Tokatli, C., Mutlu, E., Ustaoğlu, F., Islam, A. R. T., & Muhammad, S. (2024). Spatiotemporal variations, health risk assessment, and sources of potentially toxic elements in potamic water of the Anday Stream Basin (Türkiye), Black Sea Region. Environmental Monitoring and Assessment, 196(5), 420.
Yaşar İsmail, T. S., İsmail, M. D., Çobanoğlu, H., Koç, İ., & Sevik, H. (2025). Monitoring arsenic concentrations in airborne particulates of selected landscape plants and their potential for pollution mitigation. Forestist, 75: 1-6, DOI:10.5152/forestist.2024.24071
Yigit, N., Cetin, M., Ozturk, A., Sevik, H., & Cetin, S. (2019). Varitation of Stomatal Characteristics in Broad Leaved Species Based on Habitat. Applied Ecology and Environmental Research 17 (6):12859-12868.
Yigit, N., Mutevelli, Z., Sevik, H., Onat, S.M., Ozel, H.B., Cetin, M., Olgun, C. (2021). Identification of Some Fiber Characteristics in *Rosa* sp. and *Nerium oleander* L. Wood Grown under Different Ecological Conditions. BioResources, 16(3): 5862-5874. DOI:10.15376/biores.14.3.7015-7024
Yigit, N., Öztürk, A., Sevik, H., Özel, H. B., Ramadan Kshkush, F. E., & Işık, B. (2023). Clonal Variation Based on Some Morphological and Micromorphological Characteristics in the Boyabat (Sinop/Turkey) Black Pine (*Pinus nigra* subsp. *pallasiana* (Lamb.) Holmboe) Seed Orchard. BioResources, 18(3). 4850-4865.
Zhang, X. (2019). The history of pollution elements in Zhengzhou, China recorded by tree rings. Dendrochronologia, 54, 71-77.

MEMBA Su Bilimleri Dergisi

https://dergipark.org.tr/tr/pub/memba

Impacts of Recreational Use on Soil Dynamics in Kastamonu Urban Forest

Beyza Baç[1], Senem Güneş Şen[1*]

Abstract: This study assessed the effects of recreational use intensity on soil compaction and key physical and chemical soil properties in the Kastamonu Urban Forest, Turkey. Soil penetration resistance, bulk density, organic matter pH, electrical conductivity, and soil texture were measured across three land-use types (forest, recreation area, path) at two depths (0–10 cm and 10–20 cm). Results revealed that increasing use intensity significantly elevated soil penetration resistance and bulk density values, while organic matter decreased, particularly in path and recreation areas. Forest soils consistently showed the lowest soil penetration resistance (1.18–1.48 MPa) and bulk density (0.86–0.93 g/cm³) and the highest organic matter (9–12.4%), highlighting their protective role. In contrast, path soils exhibited the highest soil penetration resistance (up to 3.7 MPa), bulk density (1.60 g/cm³), and electrical conductivity (203–205 µS/cm), indicating greater compaction and reduced soil quality. Soil pH ranged from acidic in forest areas (5.5–5.9) to near-neutral in high-use areas. Correlation analyses confirmed strong links between increased compaction and reduced organic matter, along with changes in pH and electrical conductivity. Soil texture differences, with higher sand content in intensively used areas, further contributed to compaction. These findings underscore the critical role of forested areas in maintaining soil health and highlight the need for sustainable management practices to reduce compaction in urban forests. This research contributes to understanding human impacts on urban forest soils and informs strategies to balance recreation and ecosystem conservation.

Keywords: Soil compaction, urban forest, recreational use, soil properties, Kastamonu

Kastamonu Kent Ormanında Rekreasyonel Kullanımın Toprak Dinamiklerine Etkisi

Özet: Bu çalışma, Türkiye'deki Kastamonu Kent Ormanı'nda rekreasyonel kullanım yoğunluğunun toprak sıkışması ve temel fiziksel ve kimyasal toprak özellikleri üzerindeki etkilerini değerlendirmiştir. Toprak penetrasyon direnci, hacim ağırlığı, organik madde, pH, elektriksel iletkenlik ve toprak dokusu; üç farklı kullanım alanında (orman, rekreasyon alanı, patika) ve iki derinlikte (0–10 cm ve 10–20 cm) ölçülmüştür. Sonuçlar, artan kullanım yoğunluğunun toprak penetrasyon direnci ve hacim ağırlığı değerlerini anlamlı şekilde yükselttiğini, organik madde miktarının ise özellikle patika ve rekreasyon alanlarında azaldığını ortaya koymuştur. Orman toprakları, en düşük toprak penetrasyon direnci (1.18–1.48 MPa) ve hacim ağırlığı (0.86–0.93 g/cm³) ile en yüksek organik madde içeriğini (9–12.4%) göstermiş olup; bu durum, orman alanlarının toprak sağlığını koruyucu rolünü vurgulamaktadır. Buna karşılık, patika toprakları en yüksek toprak penetrasyon direnci (3.7 MPa'ya kadar), hacim ağırlığı (1.60 g/cm³) ve elektriksel iletkenlik (203–205 µS/cm) değerlerini sergileyerek daha fazla sıkışma ve azalan toprak kalitesini göstermektedir. Toprak pH'ı, orman alanlarında asidik (5.5–5.9) değerlerden, yüksek kullanım alanlarında nötr değer aralığına kadar değişmektedir. Korelasyon analizleri, artan sıkışmanın azalan organik madde miktarıyla ve pH ile elektriksel iletkenlikteki değişimlerle güçlü bir şekilde ilişkili olduğunu doğrulamaktadır. Ayrıca, kullanım yoğunluğu fazla olan alanlarda daha yüksek kum içeriği gibi toprak doku farklılıklarının da sıkışmayı artırdığı belirlenmiştir. Bu bulgular, orman alanlarının toprak sağlığını korumadaki kritik rolünü ortaya koymakta ve kentsel ormanlarda sıkışmayı azaltacak sürdürülebilir yönetim uygulamalarının gerekliliğine işaret etmektedir. Araştırma, insan etkisinin kentsel orman toprakları üzerindeki etkilerini anlamaya katkı sağlamakta ve rekreasyon ile ekosistem koruma arasında denge kurulmasına yönelik stratejiler geliştirilmesine katkıda bulunmaktadır.

Anahtar Kelimeler: Toprak sıkışması, kent orman, rekreasyonel kullanım, toprak özellikleri, Kastamonu

Article Info (Research)

1 Kastamonu University, Faculty of Forestry, Department of Forest Engineering, Kastamonu/Turkey
***Corresponding Author:** e-mail sgunes@kastamonu.edu.tr

Citation: Baç, B. Güneş Şen, S (2025). Impacts of Recreational Use on Soil Dynamics in Kastamonu Urban Forest, MEMBA Water Sciences Journal, 11, (2) 249-262.
https://doi.org/10.58626/memba.1711199

Submission Date: 01 June 2025
Acceptance Date: 24 June 2025
Publishing Date: 28 June 2025

1. Introduction

In recent decades, rapid rural-to-urban migration has led to increasing urbanization rates and, consequently, excessive population density in cities. This has resulted in heightened physical and mental pressures on urban residents. To cope with these challenges, individuals seek opportunities for rest, travel, and leisure activities during their limited free time after work (Uzun & Müderrisoğlu, 2010). In this context, recreation areas have emerged as important spaces that fulfill various needs such as relaxation, entertainment, and picnicking. Gottman and Glikson defined recreation as the refreshing of the human mind and the revitalization of life energy, encompassing planned activities that help maintain a healthy life, work efficiently, and cope with adverse environmental conditions (Balcı & İlhan, 2008). Similarly, Mateer et al. (2021) described recreational activities as voluntary leisure pursuits that individuals engage in for relaxation, enjoyment, and personal enrichment.

Recreational activities can be broadly classified into two categories based on their spatial characteristics: "open area" and "indoor" recreation. Open area recreation includes sports such as basketball and volleyball, as well as nature-based activities like hiking, picnicking, and camping. In modern urban environments characterized by intense stress and physical demands, the need for nature-based recreation has grown significantly. Even when individuals do not actively participate, they frequently visit parks, and forests to enjoy natural scenery or breathe fresh air (Karaçar & Göker, 2017). This increasing demand and interest in open area recreation has important implications for natural communities and habitats (Kissling et al., 2009). Urban forests, which provide these free and natural spaces on the periphery of cities, host dynamic interactions between human activities and the surrounding soil, air, and vegetation (Jacsman, 1998; Niemelä, 1999). However, uncontrolled increases in recreational use can disrupt the functioning of these ecosystems and lead to adverse effects (Gathoni et al., 2022; Hubbard et al., 2022; Stachowiak et al., 2022).

Although recreational activities can contribute positively by enhancing environmental awareness and fostering a sense of nature conservation (Cole, 1995; Waltert et al., 2002; Hegetschweiler et al., 2009), they can also have negative environmental impacts on forest ecosystems, particularly soil and vegetation. Problems such as soil compaction, nutrient depletion, loss of organic matter, vegetation damage, biodiversity loss, land degradation, and environmental pollution are frequently reported consequences of intensive recreational use (Ballantyne & Pickering, 2015a; Hakim & Miyakawa, 2018; dos Santos Pereira et al., 2022). Soil compaction caused by recreational use affects bulk density, porosity, and water retention (Grieve, 2001; Andrés-Abellán et al., 2005), reducing plant productivity and altering vegetation structure (Jim, 1987; Kutiel et al., 2000). Additionally, food waste, litter, and ash residues left by visitors can alter key soil properties such as pH, organic matter content, and nutrient composition (Hart et al., 2005; Arocena et al., 2006; Cole & Spildie, 2007), subsequently affecting herbaceous vegetation composition (Zhevelev & Sarah, 2008). Long-term field observations have shown that vegetation cover, plant height, and species diversity decrease in frequently visited recreational areas (Liddle, 1997; Kutiel & Zhevelev, 2001; Malmivaara et al., 2002; Roovers et al., 2004; Rusterholz et al., 2009). The severity of these impacts depends on factors such as visitor frequency, type of recreational activity, soil and vegetation type, and seasonal use (summer or winter) (Cole, 1987; Gallet & Roze, 2001). Consequently, soil compaction has been identified as a priority research topic for developing soil protection strategies in European Union countries (Van-Camp et al., 2004).

Research on the ecological effects of recreational activities in forest ecosystems highlights that these activities directly and indirectly affect ecosystem components. Indirect impacts include habitat alterations due to soil compaction and erosion (Deluca et al., 1998; George & Crooks, 2006). Increased soil bulk density, reduced porosity, and impaired soil aeration and water movement (Kozlowski, 1999) are key physical changes that elevate the importance of soil compaction as a factor in ecosystem health. These changes can hinder plant root development and limit water and nutrient availability, ultimately reducing plant productivity (Whalley, 1995; Gómez et al., 2002; Soane & Van Ouwerkerk, 2013). Studies on soil compaction’s effects on soil organic matter, pH, and nutrient content report varying outcomes, including increases or decreases in organic matter and pH, and mixed results on nutrient composition (Amrein et al., 2005; Andres-Abellan et al., 2005; Güneş Şen & Aydın, 2024). As compaction progresses, soil moisture content typically declines, reducing infiltration capacity and water availability (Xuegang & Haosheng, 1999; Settergren & Cole, 1970). However, in sandy loam soils, compaction can sometimes increase moisture retention due to greater capillary pore space (Hammitt & Cole, 1999; Aydın & Hınıs, 2024).

The degree of soil compaction is influenced by several physical and chemical factors, including soil texture, pH, cation exchange capacity, clay particle size, organic matter content, and the presence of iron oxides and aluminum hydroxides, which affect soil cohesion (Assouline et al., 1997). In urban parks, soil compaction is primarily caused by pedestrian traffic, maintenance activities, and vehicle use. Areas adjacent to paths and roadsides often experience the most severe compaction, sometimes extending to depths of up to 50 cm (Jim, 1998a; 1998b; Toleti, 2008).

The impacts of recreational use on soil moisture are complex, shaped by factors such as compaction level, soil texture, organic matter content, forest canopy density, and exposure to sunlight and wind (Xuegang & Haosheng, 1999; Settergren & Cole, 1970; Aydın & Demirci, 2024). In particularly sensitive environments—such as transitional ecosystems and fragile areas heavily used by visitors (Yıldız et al., 2017)—environmental damage can occur that is difficult to reverse, affecting multiple ecosystem components (Liddle, 1997; Sargıncı et al., 2021).

In light of these findings, this study seeks to address the following research question: Does the intensity of recreational use in the Kastamonu Urban Forest significantly alter key physical and chemical soil properties, bulk density, pH, electrical conductivity, soil texture, and loss on organic matter?

This study aims to fill a critical gap in the literature by providing region-specific empirical data on how recreational pressure alters soil properties in an urban forest ecosystem in Turkey.

2. Materials and Methods

2.1. Study area

The study was conducted in Kastamonu Urban Forest, located approximately 11 km from the central district of Kastamonu Province in the Western Black Sea Region of Turkey (Figure 1). The area covers 29.5 hectares (OGM, 2017) and is situated at latitude 41°16′23″ N and longitude 33°46′43″ E, with an average elevation of 1102 meters. According to data from the nearest meteorological station (Airport Meteorology Station), operational since 2014, the mean annual temperature between 2014 and 2024 is 11.9°C, and the average annual precipitation is 671 mm. The Köppen climate classification categorizes the region as “warm in winter, hot in summer, rainy in all seasons (Cfb)” (Kottek, 2006; Bölük et al., 2023). The area is predominantly composed of Pinus sylvestris L., with little to no significant understory vegetation. The bedrock consists mainly of Eocene neritic limestone, characterized by medium-thick bedding, heavy jointing, and a massive gray-beige structure (Atalay, 2006; Akbaş et al., 2011).

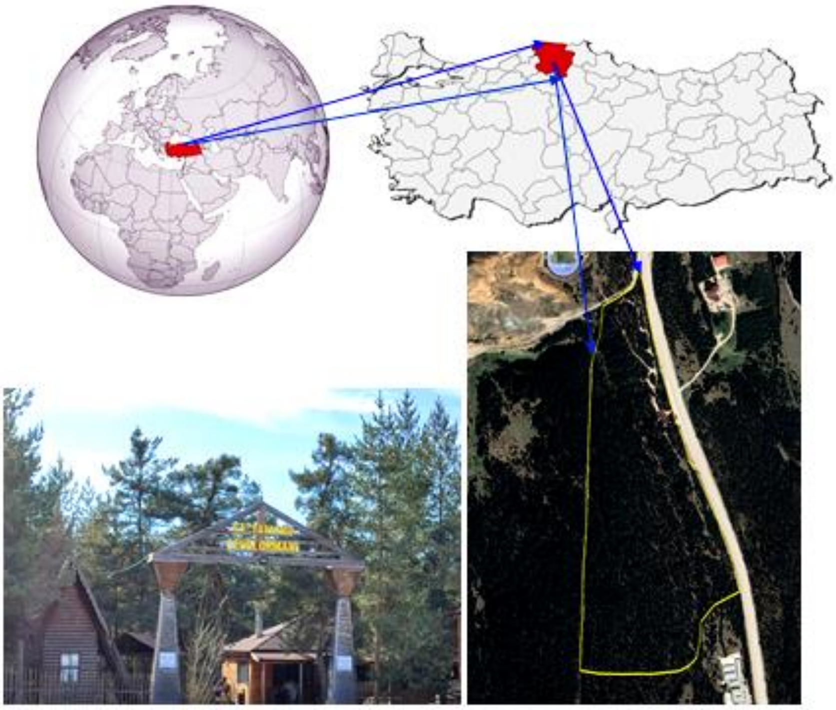


Figure 1. Location of the study area

2.2. Sampling Design and Site Classification

To assess the impact of recreational use intensity, we identified three distinct land-use types within the urban forest: path (walking routes), recreation area (picnic sites with tables and barbecues), and forest area (areas with minimal human activity). Based on field observations, the recreation area was categorized as the most intensively used, followed by path, while forest area represented the least-used areas (Figure 2). Although exact visitor counts were not available, intensity classifications were based on direct field observations, frequency of human activity, and infrastructure presence (e.g., picnic tables, grills, walking trails).

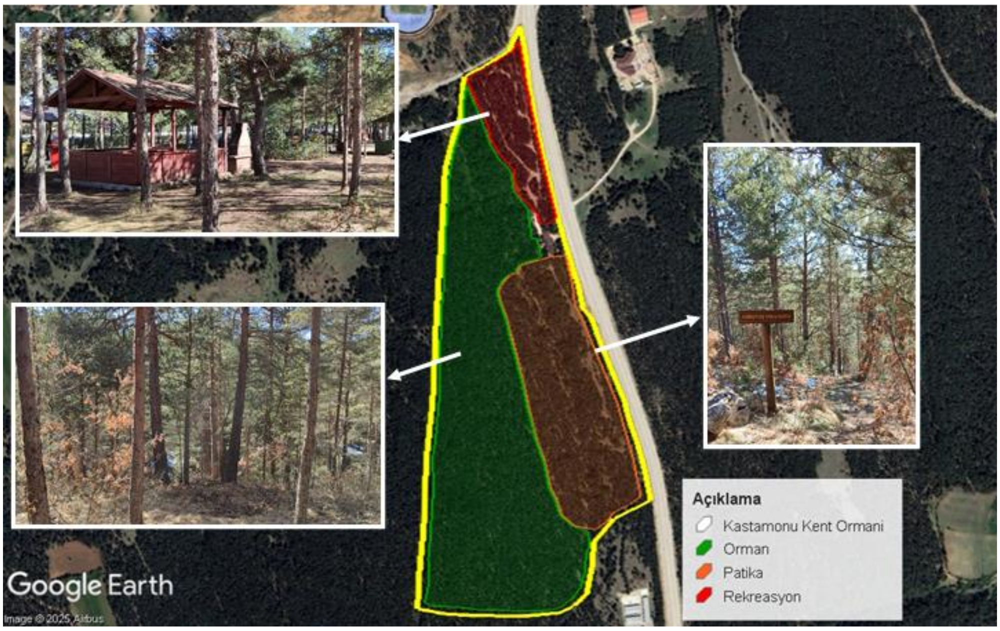


Figure 2. Study area identified according to intensity of use (Red: recreation area, Orange: pathway, Green: forest area)

2.3. Field Data Collection and Soil Analysis

We randomly selected 30 sampling points in each of the three land-use types, totaling 90 sampling sites. At each point, soil compaction was measured using a hand penetrometer set at a 30° angle (Adedokun et al., 2023). A 30° insertion angle was chosen to minimize surface resistance artifacts and ensure consistent depth penetration across varying terrain. Measurements were taken at two depth levels (0–10 cm and 10–20 cm) and classified using the USDA (1993) soil penetration resistance scale (Table 1).

Table 1. Soil penetration resistance classification

Penetration resistance (MPa)	Class
< 0,01	Extremely Low
0,01 – 0,1	Very Low
0,1 – 1,0	Low
1,0 – 2,0	Moderate
2,0 – 4,0	High
4,0 – 8,0	Very High
> 8,0	Extremely High

To analyze physical and chemical soil properties, we collected both disturbed and undisturbed soil samples from each point at both depth levels. In the laboratory, pH and electrical conductivity (EC) were determined by preparing a 1:2.5 soil-to-water suspension and using digital pH and EC meters (Özyuvacı, 1971). Soil texture was analyzed using the hydrometer method (Bouyoucos, 1936; Gülçur, 1974) and classified according to the USDA soil texture triangle (USDA, 1987). Organic matter content was estimated by igniting soil samples in a oven at 800°C for 2 hours and calculating weight loss (Gülçur, 1974).

Bulk density was determined using 5 cm steel cylinders for undisturbed soil samples. The bulk density was calculated by dividing oven-dry soil weights by the volume of the cylinder (Özyuvacı, 1976). All laboratory analyses were conducted at the Watershed Management Laboratory, Faculty of Forestry, Kastamonu University.

2.4. Statistical Analysis

We first evaluated whether the data followed a normal distribution by examining skewness and kurtosis coefficients, considering values within ±1.5 (Tabachnick & Fidell, 2013) and ±2 (George & Mallery, 2010) as acceptable. When normality was confirmed, we applied one-way ANOVA or Welch ANOVA to assess differences between land-use types. Post-hoc tests were used to identify specific group differences. For non-normally distributed data or variance was not homogeneous, we used the Kruskal-Wallis test. Finally, we conducted Spearman correlation analyses to assess the strength and direction of associations between soil compaction and other measured soil properties.

3. Results and Discussion

The mean values of soil compaction and some soil properties measured according to different usage densities and depths in Kastamonu Urban Forest are given in Table 2.

Table 2. Soil properties in different land uses (0–10 cm and 10–20 cm depths)

Depth (cm)	Land Use	SPR (MPa)	OM (%)	BD (g/cm³)	pH	EC (µS/cm)	Sand (%)	Silt (%)	Clay (%)
		Mean ± SD	Mean± SD	Mean ± SD	Mean± SD	Mean± SD	Mean ± SD	Mean ± SD	Mean± SD
0–10	Forest Area	1.10 ± 0.34	12.36 ± 2.30	0.93 ± 0.26	5.90 ± 0.41	132.8± 24.397	44.6 ± 6.10	33.4 ± 5.31	21.9 ± 2.51
	Recreation Area	2.33 ± 0.54	7.76 ± 1.37	1.25 ± 0.13	7.38 ± 0.40	137.1± 24.19	61.36 ± 9.53	22.21 ±10.86	16.44 ± 4.91
	Path	2.81 ± 0.65	5.10 ± 1.07	1.52 ± 0.35	7.70 ± 0.44	205.6± 60.893	49.6 ±10.78	34.5 ± 7.44	15.9 ± 5.08
10–20	Forest Area	1.48 ± 0.44	8.96 ± 1.44	0.86 ± 0.10	5.45 ± 0.17	142.4± 29.431	48.72 ± 7.78	27.28 ± 7.38	23.99 ± 6.12
	Recreation Area	2.23 ± 0.39	6.46 ± 0.99	1.23 ± 0.15	7.82 ± 0.57	128.1± 21.435	58.14 ± 6.11	22.26 ± 3.95	19.59 ± 5.32
	Path	3.70 ± 0.72	5.40 ± 0.84	1.60 ± 0.32	6.70 ± 0.48	203.2± 59.775	48.8 ± 7.29	30.4 ± 5.59	20.9 ± 7.88

The statistical analysis results demonstrated significant differences in topsoil properties (0–10 cm depth) among the various land-use types ($p < 0.01$). Effect sizes (η^2) were generally high, ranging from 0.29 to 0.78, suggesting a strong differentiation in soil characteristics between the groups. Post-hoc comparisons indicated that the most pronounced differences occurred between the forest (F) and recreation (R) areas. The Kruskal-Wallis test for electrical conductivity (EC) further confirmed that EC values varied significantly across the groups. Overall, the findings highlight that land use intensity significantly influences soil quality. Forest areas (F) maintained superior soil structure, characterized by higher organic matter content and lower bulk density (BD) and soil penetration resistance (SPR), compared to the recreation (R) and path (P) areas. In contrast, the recreation and path areas exhibited more pronounced soil compaction and greater organic matter depletion, reflecting the impact of intensive human activity (Table 3).

Table 3. Statistical test results (ANOVA, Welch ANOVA, Kruskal-Wallis) for topsoil (0–10 cm) soil properties across different land-use intensities

	One Way ANOVA					**Post-Hoc Test**				
	Levene's Test p	**Test Used**	**F(df$_1$, df$_2$) / H**	**p-value**	**η²**	**Test**	I-J	**Mean Diff. / H**	**Std. Err.**	**p-value**
SPR	0.007	W	75.27(2, 87)	<0.001	0.63	Th	F – R	-1.146	0.117	0.000
							F – P	-1.631	0.135	0.000
							R – P	-0.485	0.155	0.009
OM	0.000	W	147.45(2, 87)	<0.001	0.77	Th	F – R	4.598	0.489	0.000
							F – P	7.291	0.462	0.000
							R – P	2.693	0.317	0.000
BD	0.000	W	38.16(2, 87)	<0.001	0.47	Th	F – R	-0.323	0.053	0.000
							F – P	-0.596	0.080	0.000
							R – P	-0.273	0.069	0.001
pH	0.585	A	154.05(2, 87)	<0.001	0.78	T	F – R	-1.430	0.107	0.000
							F – P	-1.780	0.107	0.000
							R – P	-0.350	0.107	0.005
Sand	0.001	W	27.32(2, 87)	<0.001	0.39	Th	F – R	-16.774	2.066	0.000
							R – P	11.783	2.628	0.000
Silt	0.001	W	17.97(2, 87)	<0.001	0.29	Th	F – R	5.537	1.006	0.000
							F – P	6.029	1.034	0.000
Clay	0.004	W	20.71(2, 87)	<0.001	0.32	Th	F – R	11.239	2.207	0.000

EC	—	KW	H = 41.631	<0.001	0.46		F – R	-3.983	6.744	0.555
							F – P	-39.517	6.744	<0.001
							R - P	-35.533	6.744	<0.001

Note: $p < 0.05$ significant differences, η² values are effect size. I–J: Pairwise group comparison KW: Kuruskall-Wallis, W: Welch test, A: ANOVA, Th: Tamhane, T: Tukey, F: Forest area, R: recreacional area, P: path, SPR: Soil Penetration Resistance (MPa); OM: Organic Matter (%); BD: Bulk Density (g/cm3); EC: Electrical conductivity; Electrical Conductivity (µS/cm), Sand (%), Silt (%), Clay (%)

The results indicate that usage intensity exerts significant and statistically robust effects on subsoil properties at the 10–20 cm depth ($p < 0.001$). The effect sizes (η²) were generally high, ranging from 0.07 to 0.83, highlighting strong differentiation in soil characteristics between the land-use types. The findings reveal that soil degradations, including compaction, organic matter loss, increased pH, and dissolved salt accumulation, are particularly pronounced in path and recreation areas compared to forested areas. The protective and ameliorative role of forest cover in maintaining soil quality was clearly demonstrated. Overall, intensive human activity in recreation and path areas has led to substantial soil degradation (Table 4).

Table 4. Statistical test results (ANOVA, Welch ANOVA, Kruskal-Wallis) for subsoil (0–10 cm) soil properties across different land-use intensities

	One Way Anowa					Post- Hoc test				
	Levene's Test p	**Test Used**	**$F(df_1, df_2)$ / H**	**p-value**	**η²**	**Test**	**I-J**	**Mean Diff./H**	**Std. Err.**	**p-value**
SPR	0.000	W	103.590 (2, 87)	<0.001	0,75	Th	F – R	-0,75	0,139	0.000
							F – P	-2,221	0,139	0.000
							R – P	-1,471	0,139	0.000
OM	0.003	W	68.729 (2, 87)	<0.001	0,65	Th	F – R	2,504	0,289	0.000
							F – P	3,587	0,289	0.000
							R – P	1,083	0,289	0,001
BD	0.000	W	118.073 (2, 87)	<0.001	0,68	Th	F – R	-0,374	0,055	0.000
							F – P	-0,747	0,055	0.000
							R – P	-0,373	0,055	0.000
pH	0.000	W	303.814 (2, 87)	<0.001	0,83	Th	F – R	-2,369	0,114	0.000
							F – P	-1,300	0,114	0.000
							R – P	1,069	0,114	0.000
Sand	0.532	A	17.522 (2, 87)	<0.001	0,28	T	F – R	-9,418	1,831	0.000
							F – P	-0,061	1,831	0.999
							R – P	9,357	1,831	0.000
Silt	0.211	A	3.597 (2, 87)	<0.001	0,07	T	F – R	4,404	1,686	0,028
							F – P	3,089	1,686	0,165
							R – P	-1,314	1,686	0,716
Clay	0.038	W	22.134 (2, 87)	0<0.001	0,25	T	F – R	5,023	1,500	0,003
							F – P	-3,104	1,500	0,102
							R – P	-8,127	1,500	0.000
EC		KW	H=34.856	<0.001	0.38		F – R	13,300	6,744	1,972
							F – P	-39,150	6,744	-5,805
							R - P	-25,850	6,744	-3,833

Note: $p < 0.05$ significant differences, η² values are effect size. I–J: Pairwise group comparison KW: Kuruskall-Wallis, W: Welch test, A: ANOVA, Th: Tamhane, T: Tukey, F: Forest area, R: recreacional area, P: path, SPR: Soil Penetration Resistance (MPa); OM: Organic Matter (%); BD: Bulk Density (g/cm3); EC: Electrical conductivity; Electrical Conductivity (µS/cm), Sand (%), Silt (%), Clay (%)

The correlation analysis revealed that soil penetration resistance (SPR) is directly associated with a decrease in organic matter content and an increase in bulk density. Organic matter acts as a mitigating factor, reducing compaction by enhancing soil structure. Conversely, high visitor density in areas such as paths and recreation areas contributes to increased bulk density, thereby exacerbating soil compaction. Soil pH and electrical conductivity (EC) showed slight to moderate correlations with compaction, suggesting that compaction can influence soil chemistry and potentially alter plant growth conditions. Additionally, the proportions of sand, clay, and silt, which define soil texture, indirectly influence compaction. Specifically, soils with higher clay content exhibit a greater tendency for compaction, whereas sandy soils maintain a more permeable and less compacted structure (Table 5).

Table 5. Correlation of soil compaction and other soil properties

	Mean	SD.	SPR	OM	BD	pH	EC	Sand	Silt	Clay
SPR	2,29	0,99	1							
OM	7,67	2,86	-,641**	1						
BD	1,23	0,36	,640**	-,583**	1					
pH	6,84	0,99	,419**	-,552**	,439**	1				
EC	158,19	51,86	,400**	-,436**	,344**	0,120	1,000			
Sand	51,86	9,94	0,020	-,149*	0,116	,305**	-0,044	1		
Silt	19,81	6,18	-0,113	,192**	-,230**	-,305**	-0,087	-,522**	1	
Clay	28,35	8,55	0,057	0,040	0,043	-0,142	0,100	-,770**	-0,129	1

** $p < 0.01$ * $p < 0.05$

Soil penetration resistance (SPR) ranged from 1.18 MPa to 1.48 MPa in forest areas, 2.23 MPa to 2.33 MPa in recreation areas, and 2.81 MPa to 3.70 MPa in path areas. The lowest SPR values were consistently observed in forest areas at both depth levels. Welch test results indicated that the most significant difference in SPR occurred between forest and path areas (-2.221 ± 0.139; $p < 0.001$). Overall, soil penetration resistance increased in direct proportion to usage intensity. According to the USDA (1993) classification, soils in recreation and path areas exhibited high compaction levels, whereas forest soils exhibited only moderate compaction (Figure 3). A strong negative correlation was found between SPR and organic matter content ($r = -0.641$, $p < 0.01$), indicating that organic matter mitigates compaction. Moderate positive correlations were observed between SPR and both pH and EC ($r = 0.419$, $p < 0.01$), suggesting that compaction influences soil chemical properties and may affect plant growth. A strong positive correlation was also observed between SPR and bulk density ($r = 0.640$, $p < 0.01$), confirming that higher compaction is associated with increased soil density. Collectively, these findings demonstrate that higher usage intensity significantly increases soil compaction, as reflected in elevated penetration resistance values. These results are consistent with previous studies (Liddle & Thyer, 1986; Coder, 2000; Talbot et al., 2003; Lei, 2004; Mingyu et al., 2009; Kissling et al., 2009; Adedokun et al., 2023; Savacı & Abodkar, 2024), which also identified a linear relationship between usage intensity and soil penetration resistance. Furthermore, soil loss has been reported to accompany soil compaction in recreational and intensively used areas (Marion & Cole, 1996; Pimentel & Kounang, 1998; Güngör, 2018).

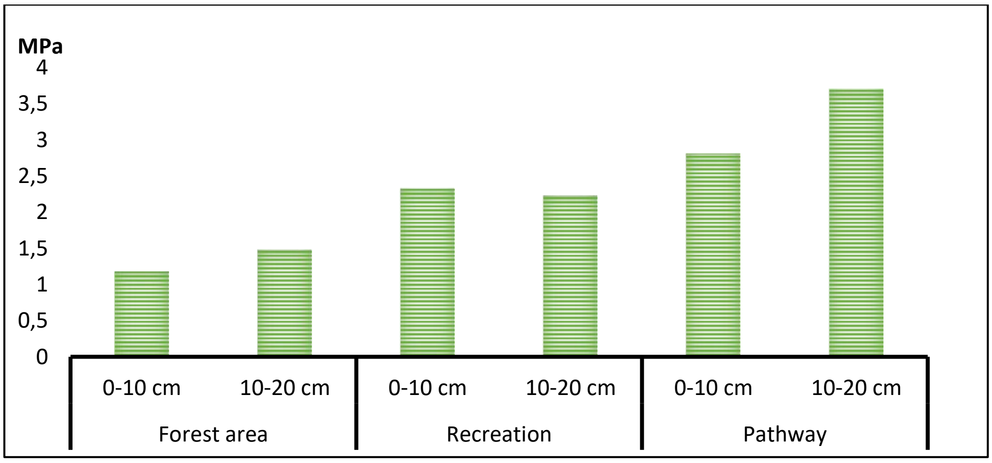


Figure 3. Variation in soil penetration resistance across land-use types (0–10 cm and 10–20 cm)

Bulk density (BD), a key indicator of soil compaction, ranged from 0.86 g/cm³ to 0.93 g/cm³ in forest areas, 1.23 g/cm³ to 1.25 g/cm³ in recreation areas, and 1.52 g/cm³ to 1.60 g/cm³ in path areas. Forest soils consistently exhibited lower BD values compared to soils in recreation and path areas. The most pronounced difference in BD was observed between forest and path areas ($p < 0.001$). These results highlight that intensified human activity in recreation and path areas substantially increases bulk density and, consequently, soil compaction. A strong negative correlation was found between BD and organic matter ($r = -0.583$, $p < 0.01$), indicating that higher organic matter content leads to reduced bulk density and mitigates compaction. Furthermore, a strong positive correlation between SPR and BD ($r = 0.640$, $p < 0.01$) reinforces the link between soil density and compaction. In recreational and path areas with high visitor density, bulk density increased significantly, limiting soil porosity and restricting root development, while low bulk density in forest areas reflected better soil structure (Figure 4). Previous studies (Kozlowski, 1999; Coder, 2000; Lei, 2004; Kissling et al., 2009; Korkanç, 2014; Adedokun et al., 2023) similarly demonstrated that recreational activities significantly increase bulk density and compaction while reducing porosity. According to Çelik and Erkmen (1999), very high bulk density reduces infiltration rates and nitrogen cycling and increases surface runoff in soils.

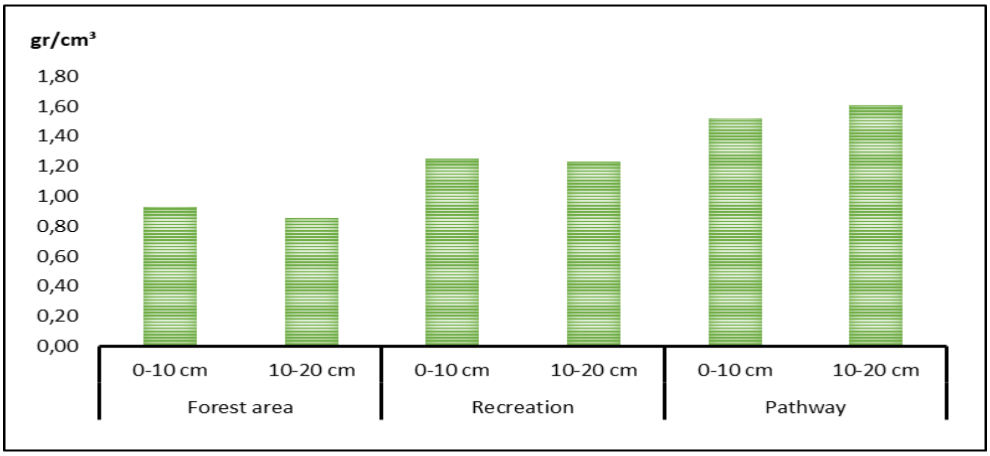


Figure 4. Variation in bulk density across land-use types (0–10 cm and 10–20 cm)

Organic matter (OM) content, a key indicator of soil water retention capacity, fertility, and microbial activity, was highest in forest areas (12.4% and 9% at both soil depths). In contrast, the lowest OM values were consistently observed in the path areas (5.1% and 5.4%). While forest areas maintained high OM content, significant reductions were noted in recreation and path areas. The forest-path comparison revealed substantial differences in OM, with a 7.291 ± 0.462 ($p < 0.001$) difference in topsoil and a 3.587 ± 0.289 ($p < 0.001$) difference in subsoil, underscoring the vital role of forest ecosystems in the organic matter cycle. Conversely, intensive use in path areas accelerated OM loss (Burden & Randerson, 1972). Overall, OM content decreased in parallel with increasing usage intensity. Strong negative correlations were observed between OM and both bulk density ($r = -0.583$, $p < 0.01$) and pH ($r = -0.552$, $p < 0.01$). Higher OM content improves soil structure and reduces bulk density, thereby mitigating compaction. Increased OM also contributes to the production of organic acids and microbial activity, leading to decreased pH, which may negatively impact soil fertility and biological processes (Figure 5). These results align with previous studies (Grieve, 2001; Yüksek, 2009; Çakır et al., 2010; Korkanç, 2014), which reported lower OM levels in recreational areas with high usage intensity.

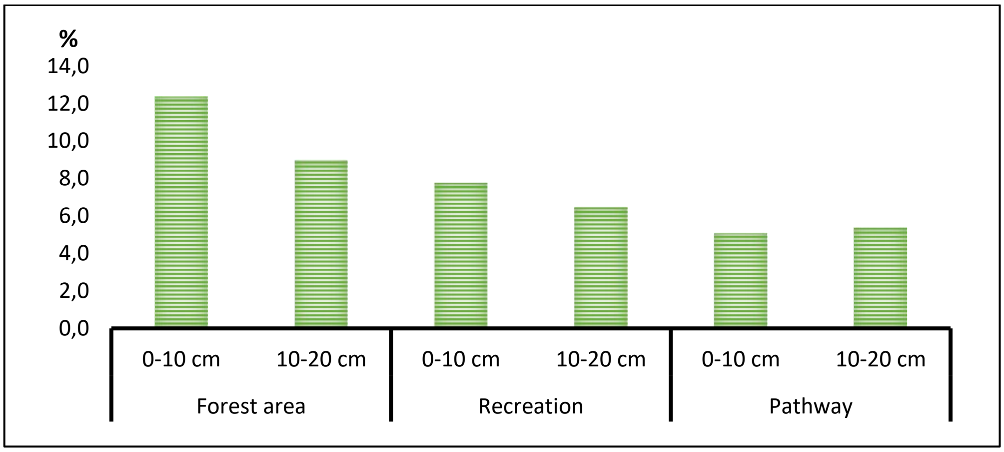


Figure 5. Variation in organic matter across land-use types (0–10 cm and 10–20 cm)

In forest areas with low usage intensity, soil pH ranged from 5.5 to 5.9, indicating an acidic environment. In contrast, recreation areas with the highest usage intensity exhibited neutral to near-neutral pH values, ranging from 7.38 to 7.82. Path areas displayed neutral pH values between 6.7 and 7.7. Significant differences in soil pH were observed across the groups, with the path area showing particularly high pH differences in both topsoil and subsoil ($p < 0.001$). These patterns suggest that topsoil loss and alkaline soil reactions are dominant in path areas. In high-use areas, enhanced organic matter mineralization and increased soil base content contributed to elevated pH (Figure 6). Conversely, pH values decreased in areas with lower usage intensity and reduced compaction. The strongest negative correlation was found between pH and organic matter (r = -0.552, p < 0.01), while the strongest positive correlations were observed with bulk density (r = 0.439, p < 0.01) and soil penetration resistance (r = 0.419, p < 0.01). Soil pH is closely linked to soil structure (loose versus compact), organic matter content, and textural properties. Consistent with the present findings, several studies have reported pH increases with usage intensity (Kutiel et al., 2000; Sarah & Zhevelev, 2007). However, other studies have found no significant changes in pH (Lei, 2004; Kissling et al., 2009; Korkanç, 2014), while some suggest that compacted soils may exhibit more acidic conditions due to organic matter loss (Burden & Randerson, 1972; Monti & Mackintosh, 1979).

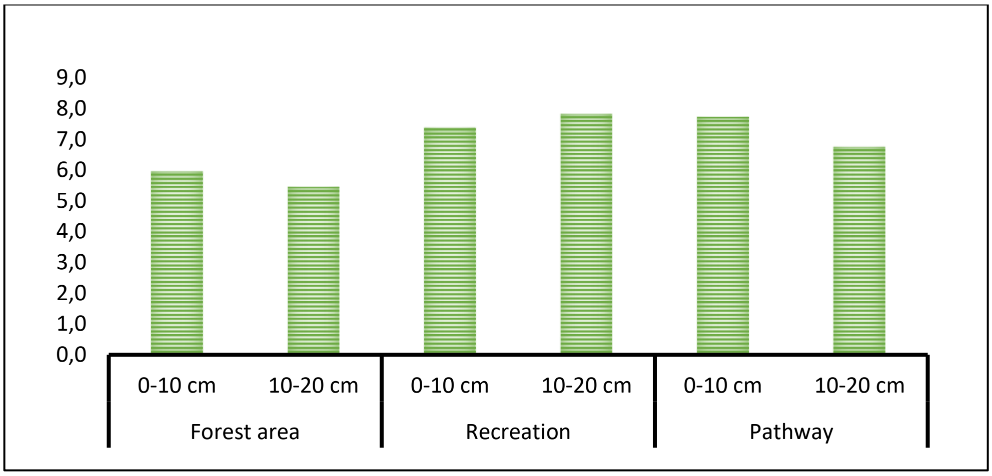


Figure 6. Variation in pH across land-use types (0–10 cm and 10–20 cm)densities

Electrical conductivity (EC) values ranged from 132 µS/cm to 142 µS/cm in forest soils, 128 µS/cm to 137 µS/cm in recreation area soils, and 203 µS/cm to 205 µS/cm in path soils (Figure 7). Kruskal-Wallis test results indicated that the highest EC values were consistently observed in path areas (H = 41.631 and H = 34.856; p < 0.001). Elevated EC levels in path areas suggest increased dissolved salt concentrations, likely resulting from intensive use and topsoil loss. This is particularly important given the implications for soil fertility and plant nutrient uptake (Sarah et al., 2016). A moderate negative correlation was observed between EC and organic matter (r = -0.436, p < 0.01), indicating that organic matter can mitigate salt accumulation. Conversely, a moderate positive correlation between EC and soil compaction (r = 0.400, p < 0.01) suggests that compaction can enhance soil salinity by restricting ion movement.

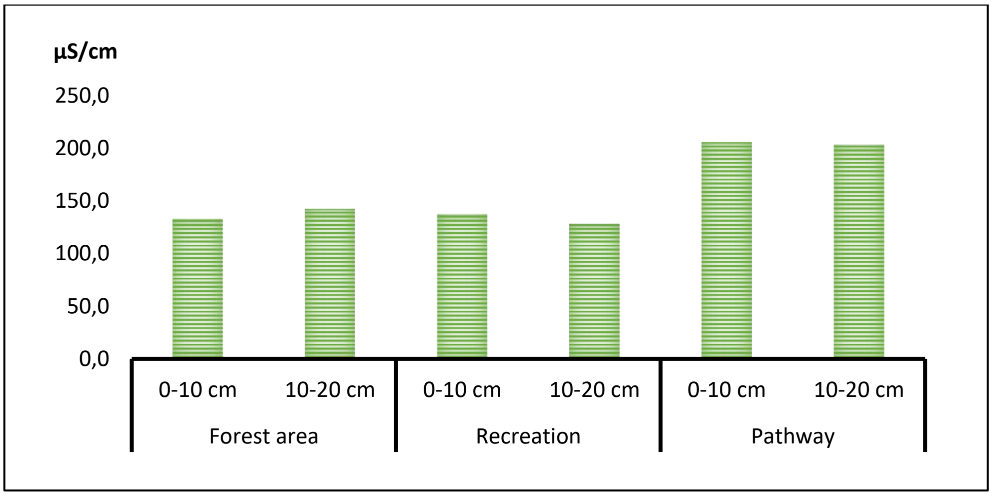


Figure 7. Variation in EC across land-use types (0–10 cm and 10–20 cm)

The soil texture for the 0–10 cm and 10–20 cm depth is presented in Figure 8. Based on international grain size classification, the soils in all three land-use types were classified as sandy clay loam (Çepel, 1996). In the topsoil, the sand content in recreation areas—where use intensity is highest—was approximately 1.5 times greater than in forest and path areas. Soil texture analysis revealed that forest areas had a more balanced and stable structure, with a significantly lower sand ratio compared to recreation areas (p < 0.001). The forest soils also exhibited higher silt and clay contents, underscoring the erosion prevention and soil stabilization functions of forest cover. In the subsoil, the recreation area again had the highest sand content, while the lowest clay content was observed in recreation areas at both depth levels. Silt content was consistently lowest in recreation and path areas. A strong negative correlation was found between sand and clay content ($r = -0.770$, $p < 0.01$). Overall, sand and clay densities were shown to vary according to land-use type; in high-use areas, clay content decreased while sand content increased. Previous research suggests that when clay content drops below 35%, soil becomes more susceptible to compaction, negatively affecting plant root development (McKyes, 1985).

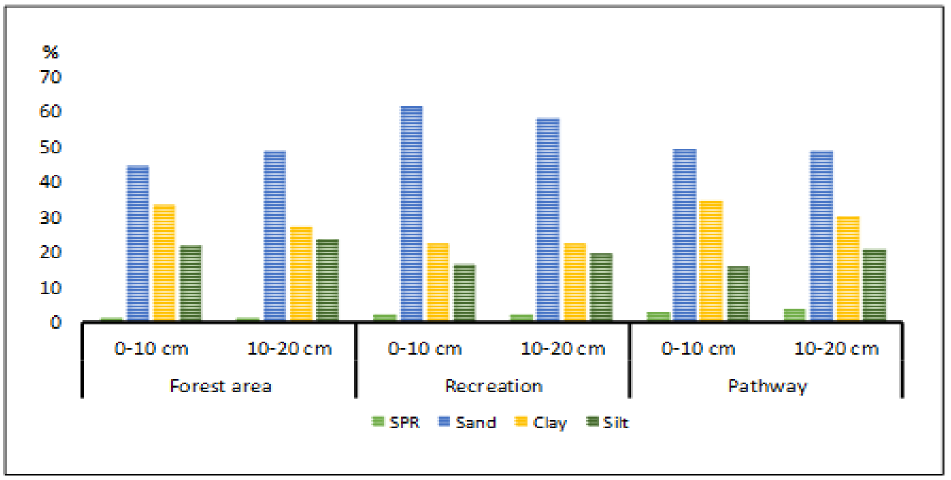


Figure 8. Variation in soil texture across land-use types (0–10 cm and 10–20 cm)

4. Conclusion

This study reveals that recreational activities significantly affect soil properties in the Kastamonu Urban Forest, with the most intense usage in path and recreation areas. The increased visitor density in these areas led to substantial soil compaction, reflected in higher soil penetration resistance and bulk density, alongside a decrease in organic matter and changes in pH and electrical conductivity. These findings underscore the importance of regulating human activity to maintain soil health. Future studies should explore the comparative effectiveness of biological, chemical, and physical soil improvement methods to inform sustainable management strategies and long-term planning for urban forest ecosystems.

5. Acknowledgement

This study was financially supported by TÜBİTAK through the "2209-A Research Project Support Programme for Undergraduate Students” with the application number of 1919B012326521.

6. Compliance with Ethical Standard

a) Author Contributions

1. SGŞ .: Conceptualization, process, software, verification, formal analysis, research, materials, authoring the first draft, composing the review, and editing, visualization, and oversigh,
2. BB.: Process, materials, data curation, authoring the first draft. The published version of the manuscript has been read and approved by both authors.

b) Conflict of Interests

There is no conflict of interest, according to the authors.

c) Statement on the Welfare of Animals

Not relevant

d) Statement of Human Rights

There are no human subjects in this study.

e) Funding

This study was supported by TÜBİTAK with the application number of 1919B012326521.

7. References

Adedokun, B.C., McHenry, M.T. & Kirkpatrick, J.B. 2023. Informal camping on the margin of wild country: Early indicators of degradation and potential for some positive nature conservation outcomes. Land Degradation & Development 34: 3867-3880. doi:10.1002/ldr.4722.

Akbaş, B., Akdeniz, N., Aksay, A. & et al. 2011. 1:1.250 000 ölçekli Türkiye Jeoloji Haritası. Maden Tetkik ve Arama Genel Müdürlüğü Yayını, Ankara, Türkiye.

Amrein, D., Rusterholz, H.-P. & Baur, B. 2005. Disturbance of suburban Fagus forests by recreational activities: effects on soil characteristics, above-ground vegetation and seed bank. Applied Vegetation Science 8: 175-182.

Andres-Abellan, M., Benayas del Alamo, J., Landete-Castillejos, T., Lopez-Serrano, F.R., Garcia-Morote, F.A. & Del Cerro-Barja, A. 2005. Impacts of visitors on soil and vegetation of the recreational area "Nacimiento del Rio Mundo" (Castilla-La Mancha, Spain). Environmental Monitoring and Assessment 101: 55-67.

Arocena, J.M., Nepal, S.K. & Rutherford, M. 2006. Visitor-induced changes in the chemical composition of soils in backcountry areas of the Mt Robson Provincial Park, British Columbia, Canada. Journal of Environmental Management 79: 10-19.

Assouline, S., Tessier, D. & Tavares-Filho, J. 1997. Effect of compaction on soil physical and hydraulic properties: Experimental results and modeling. Soil Science Society of America Journal 61(2): 390-398.

Atalay, İ. 2006. Toprak oluşumu, sınıflandırılması ve coğrafyası. Çevre ve Orman Bakanlığı Yayını, Ankara, Türkiye.

Aydın, M. ve Hınıs, AS (2024). Farklı Taç Kapanışlı Sarıçam Meşcerelerinde Bazı İklim Faktörlerinin Toprak Nemi Üzerine Etkileri. Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi , 10 (2), 85-92.

Aydın, M., & Demirci, K. (2024). Farklı Arazi Kullanımlarının Yüzeysel Akış Üzerindeki Etkileri. Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi, 10(2), 43-54.

Balcı, V. & İlhan, A. 2006. Türkiye'deki üniversite öğrencilerinin rekreatif etkinliklere katılım düzeylerinin belirlenmesi. Spormetre Beden Eğitimi ve Spor Bilimleri Dergisi 4(1): 11-18.

Ballantyne, M. & Pickering, C.M. 2015a. The impacts of trail infrastructure on vegetation and soils: Current literature and future directions. Journal of Environmental Management 164: 53-64. doi:10.1016/j.jenvman.2015.08.032

Bölük, E., Eskioğlu, O., Çalık, Y. & Yağan, S. 2023. Köppen iklim sınıflandırmasına göre Türkiye iklimi. T.C. Çevre Şehircilik ve İklim Değişikliği Bakanlığı Meteoroloji Genel Müdürlüğü, İklim ve Zirai Meteoroloji Dairesi Başkanlığı, İklim ve İklim Değişikliği Şube Müdürlüğü, Ankara, Türkiye.

Bouyoucos, G.J. 1936. Directions for making mechanical analysis of soils by the Hydrometer method. Soil Science 42(3): 225-229.

Burden, R.F. & Randerson, P.F. 1972. Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas. Journal of Applied Ecology 9: 439-457.

Coder, K.D. 2000. Defining soil compaction: sites & trees. Extension Publication 00-4. Warnell School of Forest Resources, University of Georgia, Athens, GA, ABD.

Cole, D.N. 1987. Effects of three seasons of experimental trampling on five montane forest communities and a grassland in Western Montana, USA. Biological Conservation 40: 219-244.

Cole, D.N. 1995. Experimental trampling of vegetation. I. Relationship between trampling intensity and vegetation response. Journal of Applied Ecology 32: 203-221.

Cole, D.N. & Spildie, D.R. 2007. Vegetation and soil restoration on highly impacted campsites in the Eagle Cap Wilderness, Oregon. Gen. Tech. Rep. RMRS-GTR 185, USDA, Fort Collins, CO, ABD, 26 s.

Çakir, M., Makineci, E. & Kumbasli, M. 2010. Comparative study on soil properties in a picnic and undisturbed area of Belgrad forest. İstanbul. Journal of Environmental Biology 31(1): 125-128.

Çelik, A. & Erkmen, Y. 1999. Toprak frezesinde değişik tip bıçaklarla toprak işlemenin kışlık buğdayda tarla filizi çıkışına ve verimine olan etkileri. Atatürk Üniversitesi Ziraat Fakültesi Dergisi 30(1): 55-62.

Çepel, N. 1996. Toprak İlmi. İstanbul Üniversitesi Yayın No: 3945, Orman Fakültesi Yayın No: 438, 286 s., İstanbul, Türkiye (Türkçe).

Deluca, T.H., Patterson IV, W.A., Freimund, W.A. & Cole, D.N. 1998. Influence of llamas, horses, and hikers on soil erosion from established recreation trails in western Montana, USA. Environmental Management

22(2): 255-262.
dos Santos Pereira, L., Rodrigues, A.M., do Carmo Oliveira Jorge, M., Guerra, A.J.T., Booth, C.A. & Fullen, M.A. 2022. Detrimental effects of tourist trails on soil system dynamics in Ubatuba Municipality, São Paulo State, Brazil. Catena 216: 106431. doi:10.1016/j.catena.2022.106431.
Gallet, S. & Roze, F. 2001. Resistance of Atlantic heathlands to trampling in Brittany (France): influence of vegetation type, season and weather conditions. Biological Conservation 97: 189-198.
Gathoni, B., Munayi, S.P. & Wanjira, J. 2022. Impact of recreation activities in the national parks on vegetation, soil, water and wild game in the Central Kenya Region. Dedan Kimathi University of Technology, Nyeri, Kenya.
George, D. & Mallery, M. 2010. SPSS for Windows step by step: A simple guide and reference, 17.0 update (10. baskı). Pearson, Boston, ABD.
George, S.L. & Crooks, K.R. 2006. Recreation and large mammal activity in an urban nature reserve. Biological Conservation 133(1): 107-117.
Gomez, A., Powers, R.F., Singer, M.J. & Horwath, W.R. 2002. Soil compaction effects on growth of young ponderosa pine following litter removal in California's Sierra Nevada. Soil Science Society of America Journal 66(4): 1334-1343.
Gulcur, F. 1974. Physical and Chemical Soil Analysis Methods. İstanbul Üniversitesi Orman Fakültesi Yayınları, İstanbul, Türkiye (Türkçe).
Güneş Şen, S., & Aydın, M. 2024. Farklı Meşcere Türlerinde Ormanaltı Yağış, Gövdeden Akış ve İntersepsiyonun Belirlenmesi. Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi, 10(1), 115-123.
Güngör, B. Ş. 2018. Cultural ecosystem services and recreational use: a review study in Belgrad Forest, Istanbul. Journal of Multidisciplinary Research in Sustainability 1(1): 30-55.
Hakim, L. & Miyakawa, H. 2018. Integrating ecosystem restoration and development of recreation sites in degraded tropical mountain areas in East Java, Indonesia. AIP Conference Proceedings 2019. doi:10.1063/1.5061886.
Hammitt, W.E. & Cole, D.N. 1999. Wildland recreation ecology and management. Journal of Range Management 52: 678-678.
Hart, S.C., DeLuca, T.H., Newman, G.S., MacKenzie, M.D. & Boyle, S.I. 2005. Post-fire vegetative dynamics as drivers of microbial community structure and function in forest soils. Forest Ecology and Management 220: 166-184.
Hegetschweiler, K.T., van Loon, N., Ryser, A., Rusterholz, H.P. & Baur, B. 2009. Effects of fireplace use on forest vegetation and amount of woody debris in suburban forests in Northern Switzerland. Environmental Management 43: 299-310.
Hubbard, T., Cove, M.V. & Lafferty, D.J. 2022. Human recreation impacts seasonal activity and occupancy of American black bears (Ursus americanus) across the anthropogenic-wildland interface. Scientific Reports 12: 12201.
Jim, C.Y. 1987. Trampling impacts of recreationists on picnic sites in a Hong Kong country park. Environmental Conservation 14(2): 117-127.
Jim, C.Y. 1998a. Soil characteristics and management in an urban park in Hong Kong. Environmental Management 22: 683-695.
Jim, C.Y. 1998b. Urban soil characteristics and limitations for landscape planting in Hong Kong. Landscape and Urban Planning 40: 235-249.
Karaçar, E. & Göker, G. 2017. Orman içi rekreasyon alanlarının ekolojik açıdan incelenmesi. Journal of Recreation and Tourism Research 4(4): 35-42.
Kissling, M., Hegetschweiler, K.T., Rusterholz, H.P. & Baur, B. 2009. Short-term and long-term effects of human trampling on above-ground vegetation, soil density, soil organic matter and soil microbial processes in suburban beech forests. Applied Soil Ecology 42(3): 303-314.
Korkanç, S.Y. 2014. Impacts of recreational human trampling on selected soil and vegetation properties of Aladag Natural Park, Turkey. Catena 113: 219-225.
Kottek, M., Grieser, J., Beck, C., Rudolf, B. & Rubel, F. 2006. World map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift 15: 259-263.
Kozlowski, T.T. 1999. Soil compaction and growth of woody plants. Scandinavian Journal of Forest Research 14: 596-619.
Kutiel, P. & Zhevelev, Y. 2001. Recreational use impact on soil and vegetation at picnic sites in Aleppo pine forests on Mount Carmel, Israel. Israel Journal of Plant Sciences 49: 49-56.
Kutiel, P., Zhevelev, H. & Lavee, H. 2000. Coastal dune ecosystems: Management for conservation objective. III. Soil response to three vegetation types to recreational use. Journal of Mediterranean Ecology 1: 171-179.
Lei, S.A. 2004. Soil compaction from human trampling, biking, and off-road motor vehicle activity in a blackbrush (Coleogyne ramosissima) shrubland. Western North American Naturalist 64(1): 125-130.

Liddle, M.J. 1997. Recreation Ecology: The Ecological Impact of Outdoor Recreation and Ecotourism. Springer, 639 s.

Liddle, M.J. & Thyer, N.C. 1986. Trampling and fire in a subtropical dry sclerophyll forest. Environmental Conservation 13: 33-39.

Malmivaara, M., Löfström, I. & Vanha-Majamaa, I. 2002. Anthropogenic effects on understorey vegetation in Myrtillus type urban forests in southern Finland. Silva Fennica 36: 367-381.

Marion, J.L. & Cole, D.N. 1996. Spatial and temporal variation in soil and vegetation impacts on campsites. Ecological Applications 6: 520-530.

Mateer, T.J., Rice, W.L., Taff, B.D., Lawhon, B., Reigner, N. & Newman, P. 2021. Psychosocial factors influencing outdoor recreation during the COVID-19 pandemic. Frontiers in Sustainable Cities 3: 621029.

Mc Kyes, E. 1985. Soil Cutting and Tillage. Developments in Agricultural Engineering 7. Elsevier Science Publishers, B.V., Amsterdam, Hollanda.

Mingyu, Y., Hens, L., Xiaokun, O. & Wulf, R.D. 2009. Impacts of recreational trampling on sub-alpine vegetation and soils in Northwest Yunnan, China. Acta Ecologica Sinica 29: 171-175. doi:10.1016/j.chnaes.2009.07.005.

Monti, P.W. & Mackintosh, E.E. 1979. Effect of camping on surface soil properties in the boreal forest region of northwestern Ontario, Canada. Soil Science Society of America Journal 43(5): 1024-1029.

Jacsman, J. 1998. Konsequenzen der intensiven Erholungsnutzung für die Wälder im städtischen Raum. Schweizerische Zeitschrift für Forstwesen 149: 423–439.

Niemelä, J. 1999. Ecology and urban planning. Biodiversity and Conservation 8: 119-131.

OGM. 2017. Generel Directorate of Forestry, Department of Non-Wood Products and Services, Statistical Regions. Erişim tarihi: 30 Haziran 2017. https://www.ogm.gov.tr/Baskanliklar/OdunDisiUrunveHizmetler/Sayfalar/Odun-Disi-Urun-veHizmetler.aspx

Özyuvaci, N. 1971. Topraklarda erozyon eğiliminin tesbitinde kullanılan bazı önemli indeksler. İstanbul Üniversitesi Orman Fakültesi Dergisi 21: 190-207.

Özyuvaci, N. 1976. Hydrologic characteristics of the Arnavutköy Creek watershed as influenced by some plant–soil–water relations. İstanbul Üniversitesi Orman Fakültesi Yayın No: 2082. Kutulmuş Matbaası, İstanbul, Türkiye (Türkçe).

Pimentel, D. & Kounang, N. 1998. Ecology of soil erosion in ecosystems. Ecosystems 1: 416-426.

Roovers, P., Verheyen, K., Hermy, M. & Gulinck, H. 2004. Experimental trampling and vegetation recovery in some forest and heathland communities. Applied Vegetation Science 7: 111-118.

Rusterholz, H.P., Kissling, M. & Baur, B. 2009. Disturbance by human trampling alters the performance, sexual reproduction and genetic diversity in a clonal woodland herb. Perspectives in Plant Ecology, Evolution and Systematics 11: 17-29.

Sarah, P., Zhevelev, H.M. & Oz, A. 2016. Human activities modify soil properties in urban parks: a case study of Tel Aviv-Jaffa. Journal of Soils and Sediments 16: 2538-2547.

Sargıncı, M., Yeşil, Z.B., Dönmez, A.H. & Yıldız, O. 2021. İstanbul kent ormanında arazi kullanım yoğunluğuna bağlı toprak özelliklerinin değişimi. Düzce Üniversitesi Bilim ve Teknoloji Dergisi 9(2): 899-914.

Savacı, G., & Abokdar, K. M. M. 2024. Effects of Soil Compaction on Vegetation and Soil Physicochemical Properties in Recreational Areas: A Case Study of Kastamonu. Kastamonu University Journal of Forestry Faculty, 24(1), 22-40.

Settergren, C.D. & Cole, D.M. 1970. Recreation effects on soil and vegetation in the Missouri Ozarks. Journal of Forestry 68(4): 231-233.

Soane, B.D. & Van Ouwerkerk, C. 2013. Soil Compaction in Crop Production. Elsevier, Amsterdam, Hollanda.

Stachowiak, C., Crain, B.J., Kroetz, K., Sanchirico, J.N. & Armsworth, P.R. 2022. The impact of recreational use and access on biotic and abiotic disturbances on areas protected by local communities and a state conservation agency. Journal for Nature Conservation 68: 126216.

Tabachnick, B.G. & Fidell, L.S. 2013. Using multivariate statistics (6. baskı). Pearson, Boston, ABD.

Talbot, L.M., Turton, S.M. & Graham, A.W. 2003. Trampling resistance of tropical rainforest soils and vegetation in the wet tropics of North east Australia. Journal of Environmental Management 69: 63-69.

Toleti, B.V.M.R. 2008. Urban forest soil characteristics: a geostatistical analysis of Allan Gardens Park, Toronto, Canada. Master of Spatial Analysis Tezi, Department of Geography, Ryerson University, Toronto, Kanada.

USDA. 1987. Soil mechanics level I. Module 3 – USDA textural soil classification study guide. National Employee Development Staff, Soil Conservation Service, United States Department of Agriculture, Washington, DC, ABD.

USDA. 1993. Soil Survey Manual. Soil Survey Division Staff, Washington, DC, ABD, 139 s.

Uzun, S. & Müderrisoğlu, H. 2010. Kırsal rekreasyon alanlarında kullanıcı memnuniyeti: Bolu Gölcük ormaniçi dinlenme yeri örneği. Süleyman Demirel Üniversitesi Orman Fakültesi Dergisi A(1): 67-82.

Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. & Selavaradjou, S.K. 2004. Reports of the Technical Working Groups Established Under the Thematic Strategy for Soil Protection. Office for Official Publication of the European Communities, Luxemburg, EUR 21319 EN/6.

Waltert, B., Wiemken, V., Rusterholz, H.-P., Boller, T. & Baur, B. 2002. Disturbance of forest by trampling: Effects on mycorrhizal roots of seedlings and mature trees of Fagus sylvatica. Plant and Soil 243: 143-154.

Whalley, W.R., Dumitru, E. & Dexter, A.R. 1995. Biological effects of soil compaction. Soil & Tillage Research 35: 53-68.

Xuegang, F. & Haosheng, B. 1999. Studies of impacts of tourism on vegetation and soil. Journal of Natural Resources 14(1): 75-78.

Yildiz, O., Altundağ, E., Çetin, B., Güner, Ş.T., Sarginci, M. & Toprak, B. 2017. Afforestation restoration of saline-sodic soil in the Central Anatolian Region of Turkey using gypsum and sulfur. Silva Fennica 51(1B): 1-17.

Yuksek, T. 2009. Effect of visitor activities on surface soil environmental conditions and aboveground herbaceous biomass in Ayder Natural Park. Clean 37(2): 170-175.

Zhevelev, H. & Sarah, P. 2008. The effect of visitors' pressure on the spatial variability of sandy soil in an urban parks in Tel Aviv. Environmental Monitoring and Assessment 142: 35-46.