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RESEARCH ARTICLE **ARAŞTIRMA MAKALESİ**

A meta-synthesis of artificial reef studies in Türkiye

Türkiye'deki yapay resif çalışmaları üzerine bir meta-sentez

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Abstract: This paper systematically reviews artificial reef (AR) studies in Türkiye through a meta-synthesis of 43 studies (49 ARs) between 1990 and 2025. Data were coded and thematically analyzed using descriptive statistics and an AR performance scoring system was used to assess AR sites. The results show a strong concentration of AR projects in the Aegean Sea, where concrete cubic modules are typically deployed at mid-depths for protection and research. Ecological findings confirm ARs attract species like *Chromis chromis* and *Diplodus vulgaris*, but increases in species richness and abundance were reported in only about 36-38% of AR sites. Methodologically, visual census/observation predominated while long-term monitoring and socio-economic assessments were limited. An AR performance score averaged 4.07±1.02, indicating moderate success of AR studies. Key deficiencies include a lack of cost reporting, centralized coordination, short monitoring durations, and insufficient socio-economic evaluation. The study concludes that realizing the full potential of ARs in Türkiye requires integrated planning, standardized monitoring, stakeholder involvement, and multifunctional project designs.

Keywords: Artificial reef, fisheries management, meta-synthesis, reef performance, Türkiye

Öz: Bu makale, 1990 ile 2025 yılları arasında Türkiye'deki 43 yapay resif (YR) çalışmasını (49 resif alanı) meta-sentezi yoluyla sistematik olarak incelemektedir. Veriler kodlandıktan sonra betimsel istatistikler kullanılarak tematik analiz yapılmış ve bir YR performans puanlama sistemi kullanılarak YR alanları değerlendirilmiştir. Sonuçlar, YR projelerinin Ege Denizi'nde yoğunlaştığını, burada genellikle koruma ve araştırma amaçlı beton kübik modüllerin orta derinliklere yerleştirildiğini göstermektedir. Ekolojik bulgular, YR'lerin *Chromis chromis* ve *Diplodus vulgaris* gibi türleri çektiğini doğrulamakla birlikte, tür zenginliği ve birey sayısındaki artışların yalnızca yaklaşık %36-38 olduğu rapor edilmiştir. Metodolojik olarak görsel sayım/gözlem baskın yöntem iken, uzun vadeli izleme ve sosyo-ekonomik değerlendirmeler sınırlı kalmıştır. YR performans puanı ortalama 4.07±1.02 olarak hesaplanmış olup, bu sonuç YR çalışmalarının orta düzeyde başarılı olduğunu göstermektedir. YR alanlarına ilişkin incelenen çalışmaların başlıca eksiklikleri arasında proje maliyet raporlamasının olmaması, merkezi koordinasyon eksikliği, kısa izleme süreleri ve yetersiz sosyo-ekonomik değerlendirme yer almaktadır. Çalışma, Türkiye'de YR'lerin tam potansiyeline ulaşabilmesi için bütünleşik planlama, standart izleme, paydaş katılımı ve çok işlevli proje tasarımları gerektiği sonucuna varmıştır.

Anahtar kelimeler: Yapay resif, balıkçılık yönetimi, meta-sentez, resif performansı, Türkiye

INTRODUCTION

Fisheries have historically served as a fundamental source of nutrition and livelihood for humanity (Lackey, 2005). While technological advancements increased fishing capacity, overexploitation in the 20th century led to the collapse of numerous commercial stocks (Sahrhage and Lundbeck, 2012). Growing human populations and coastal pressures necessitate sustainable fisheries management (Denis et al., 2001; McClanahan et al., 2015), with FAO data indicating that maximum wild capture potential has likely been reached, a significant proportion of stocks are overexploited, and require rebuilding (Worm et al., 2009; FAO, 2020). In this context, artificial reefs have gained importance as a habitat enhancement tool for managing conflicts with fishing pressure on resources, developing commercial, and recreational fishing, creating new diving areas and increasing biodiversity (Lök, 1995; Fabi et al., 2015). ARs are employed for a wide range of objectives, from enhancing fish biomass and diversity to habitat restoration (Seaman and Sprague, 1991). The literature contains numerous studies and meta-analyses examining the ecological and socio-economic impacts of AR (e.g., Paxton et al., 2020; Bracho-Villavicencio et al., 2023; Chong et al., 2024). However, applications in Türkiye have typically progressed as regional, short-term projects with limited monitoring, lacking a systematic national-scale assessment and a synthesis study integrated with the international literature (Savut, 2013).

This study aims to fill this gap by systematically reviewing theses and articles from the period 1990-2025 using systematic review and descriptive statistics to provide a holistic evaluation of AR applications in Türkiye. Consequently, it is expected from this study to consolidate the fragmented national knowledge into an evidence-based overview and provide concrete data for developing an up-to-date national master plan and evidence-based policies.

MATERIALS AND METHODS

Materials

The materials of this study consist of master's/doctoral theses and peer-reviewed journal articles published between 1990 and 2025 that document at least one artificial reef (AR) deployment. Also, ARs must be deployed in Turkish territorial waters and involve structures intentionally deployed for a specific purpose. The primary data sources were The Council of Higher Education (YÖK) National Thesis Center, Dergipark database (supplemented by Google Scholar) and Web of Science (WoS) database (including SCIE, SSCI, AHCI, and

ESCI editions). The search was conducted with the following keywords in Turkish and English: "yapay resif" (artificial reef), "yapay yuva" (artificial nest), and "yapay habitat" (artificial habitat). Studies that did not conform to the FAO definition of artificial reefs such as floating fish aggregation devices (FADs) as well as duplicate publications, conference papers, theoretical reviews, books, and inaccessible texts were excluded.

Method and data collection

This research employed a meta-synthesis approach, supported by a systematic review protocol, to holistically evaluate AR studies conducted in Türkiye (Appendix 1). The process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework and consisted of four sequential stages: 1) Identification: Initial literature search across three databases (YÖK, Dergipark, WoS) using predefined keywords. 2) Screening: Application of inclusion and exclusion criteria: Inclusion criteria involve theses or peer-reviewed articles (1990-2025), reporting field research or findings from Türkiye and exclusion criteria involve theoretical reviews, conference abstracts, survey-only studies, duplicates, studies outside Turkish waters, and non-AR definitions (e.g., FADs). 3) Eligibility: Full-text review and coding using a standardized Excel form. 4) Inclusion: Final dataset compilation and data cleaning.

A total of 43 studies were included in the meta-synthesis after screening (Figure 1). Each study was systematically coded according to the following thematic categories: Research and reef characteristics, ecological characteristics, methodological information, and research findings. The coding and synthesis were conducted iteratively to ensure consistency and comprehensiveness in the qualitative and descriptive analysis. In cases where a single study investigated more than one distinct artificial reef site, each site was treated as an independent unit of analysis. Therefore, while the meta-synthesis is based on 43 studies, it encompasses a total of 49 individual AR locations (three studies included two reef areas each, and one study included three reef areas).

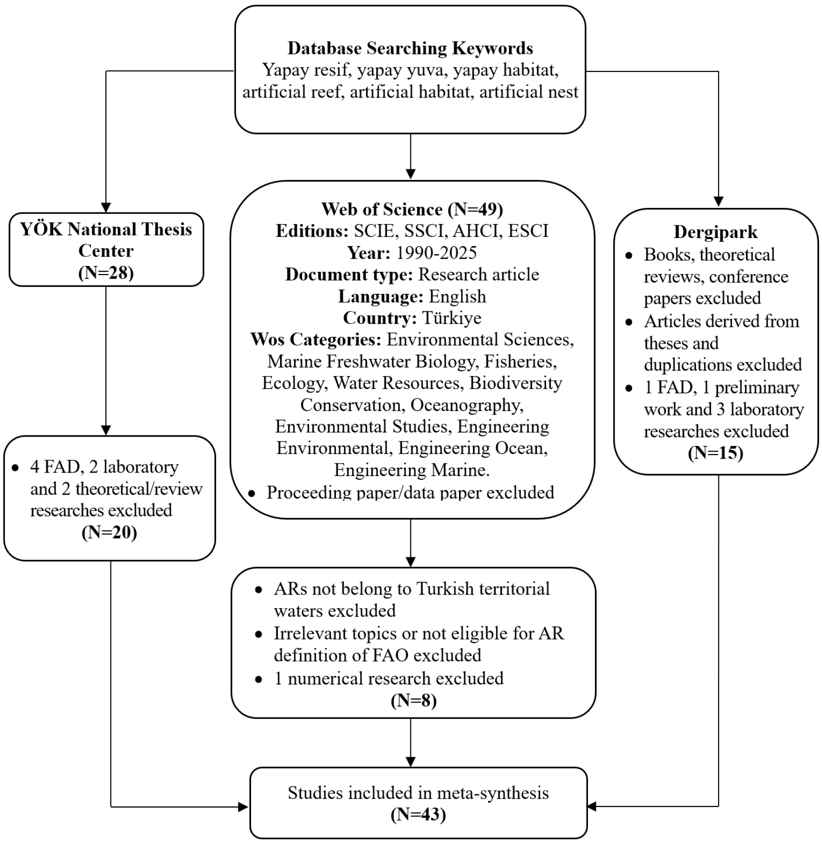

Figure 1. PRISMA diagram for meta-synthesis

After meta-synthesis, an Artificial Reef Performance Score (min. 0; max. 8 points) was calculated for each study based on eight indicators. These indicators assessed key aspects of study design, reported outcomes, and transparency including structural stability, monitoring duration, stated management objectives, reported ecological and socioeconomic benefits, sample size adequacy (relative to the study pool), and cost reporting. Each indicator was coded as 0, 0.5, or 1 point according to predefined criteria (Table 1).

Table 1. Ratings criteria for the AR performance scores (adapted from Cárdenas-Rojas et al. (2021) and Fabi et al. (2015))

Indicators	Description	Coding Criteria
1. Stability	Physical stability of the reef structure.	1: Fully stable (no damage/movement). 0.5: Partially stable (minor damage/displacement). 0: Unstable or no information.
2. Pre-Deployment Monitoring	Baseline monitoring before reef deployment.	1: ≥1 year (or 4 seasons). 0.5: Monitoring present, but <1 year. 0: No baseline monitoring.
3. Post-Deployment Monitoring	Monitoring after reef deployment.	1: ≥1 year (or 4 seasons). 0.5: Monitoring present, but <1 year. 0: No follow-up monitoring.
4. Management Objective	Explicit statement of a fisheries/ecological goal.	1: A specific objective is stated (e.g., habitat restoration, conflict resolution). 0: No objective stated.
5. Positive Ecological Outcome	Report of a beneficial ecological result.	1: At least one clear positive finding (e.g., increased biodiversity, fish aggregation). 0: No positive finding reported.
6. Positive Socioeconomic Outcome	Report of a beneficial socioeconomic result.	1: At least one clear positive finding (e.g., increased catch, improved livelihoods). 0: No positive finding reported.
7. Total Observation/ Sampling	Sufficiency of observations/samples.	1: >1 standart deviation above the mean of all reefs. 0.5: Within ±1 standart deviation of the mean. 0: >1 standart deviation below the mean or no observation data.
8. Cost Reporting	Transparency regarding project costs.	1: Project cost information provided. 0: No cost information provided.

Of the 49 reefs, 2 were related to acoustic positioning; therefore, reef performance is not applicable in these cases. Consequently, reef performance scores were calculated based on 47 of the 49 reefs included in the meta-analysis. Due to both the relatively recent emergence of artificial reef research in Türkiye and the limitations in the quality and quantity of available studies, it was not feasible to apply established scoring frameworks such as the +3 to -3 reef performance scale (Baine, 2001) or the 0-100 Artificial Reef Multimetric Index (Lima et al., 2020). Instead, a simpler assessment tool was adapted from the work of Cárdenas-Rojas et al. (2021), incorporating performance criteria from the Fabi et al. (2015) FAO guidelines. This adapted tool evaluates eight key parameters using a straightforward scoring system: Yes (1), No (0), and Partially (0.5). While the resulting scores should not be considered as absolute qualitative assessment, they provide an objective and standardized perspective on the characteristics of ARs in the reviewed studies.

Data analysis

Data analysis was performed using SPSS 25.0 and Microsoft Excel software. Within the scope of meta-synthesis, descriptive statistics (frequency, percentage) for the coded variables were calculated and thematic interpretations were made. Furthermore, AR performance scores were calculated for each study, and overall and indicator-based averages were derived and interpreted.

RESULTS

The meta-synthesis was conducted to evaluate 49 ARs, assessing their characteristics of publications and the ARs used, ecological variables, methodological information, and the presence/absence of general findings. The spatial distribution of AR sites is presented in Table 2.

Table 2. Spatial distribution of AR sites in reviewed studies

No	ARs	Water bodies	N	%
1	Edremit Bay (Altınoluk included)	Aegean Sea	10	20.41
2	Ürkmez-Gümüldür	Aegean Sea	7	14.29
3	Karaburun (Büyükada & Küçükada included)	Aegean Sea	5	10.20
4	Hekimadası	Aegean Sea	4	8.16
5	Erdek Ocaklar / Erdek Bay	Marmara Sea	3	6.12
6	İstanbul Artificial Reef Project	Marmara Sea	2	4.08
7	Kuşadası Bay (Pamucak)	Aegean Sea	2	4.08
8	TCSG-132 Shipwreck	Aegean Sea	2	4.08
9	Çeşme-Dalyanköy	Aegean Sea	2	4.08
10	Urla-İskele Island	Aegean Sea	1	2.04
11	Gökçeada Underwater Park	Marmara Sea	1	2.04
12	Sinop Inner Harbor	Black Sea	1	2.04
13	Çanakkale Underwater and Search & Rescue Sports Club Underwater Station	Marmara Sea	1	2.04
14	Bodrum Karaada	Aegean Sea	1	2.04
15	Adana Yumurtalık	Mediterranean Sea	1	2.04
16	İzmir Bay Urla Coast	Aegean Sea	1	2.04
17	Antalya Konyaaltı	Mediterranean Sea	1	2.04
18	Ordu Ünye	Black Sea	1	2.04
19	Ordu Mersin Village	Black Sea	1	2.04
20	İskenderun Bay	Mediterranean Sea	1	2.04
21	Mersin Silifke Akkum	Mediterranean Sea	1	2.04
	Total		**49**	**100.00**

The first nine locations account for 71.50% of the total 49 ARs, indicating a strong spatial concentration of studies. Edremit Bay (including Altınoluk) represents 20.41% of ARs, followed by Ürkmez-Gümüldür (14.29%) and they jointly forming the core areas where research activity is most intensive. Together with Hekimadası (8.16%) and Karaburun (10.20%), these four locations alone comprise 53.06% of all cases, demonstrating a pronounced clustering along the Aegean coast. The remaining five locations within the top nine such as Erdek Ocaklar / Erdek Bay, İstanbul Artificial Reef Project, Kuşadası Bay (Pamucak), TCSG-132 Shipwreck, and Çeşme-Dalyanköy reflect more localized or project-specific implementations. The distribution of 43 AR research type and 49 AR site characteristics are presented in Table 3.

Table 3. Themes related to ARs and research characteristics ("n" denotes the frequency (number of studies), while "%" indicates the percentage corresponding to each category.)

Research Themes		N	%
Research Type	Master's thesis	14	32.56
	Doctoral thesis	6	13.95
	Research articles	23	53.49
Reef Region	Aegean	36	73.47
	Marmara	6	12.24
	Mediterranean	4	8.16
	Black Sea	3	6.12
Reef Design	Cubic	24	35.82
	Pentagonal dome	6	8.96
	Shipwreck	6	8.96
	Cylindrical	4	5.97
	Other	19	28.36
	No information	8	11.94
Reef Material	Concrete	38	56.72
	Ship/aircraft/bus	9	13.43
	Steel/iron	7	10.45
	Wood	3	4.48
	Tire	3	4.48
	Other	6	8.96
	No information	1	1.49
Reef Depth	Shallow (0-15 m)	8	16.33
	Medium (15-30 m)	31	63.27
	Deep (over 30 m)	5	10.20
	No information	5	10.20
Reef Volume	0-100 m³	11	22.45
	100-1000 m³	13	26.53
	Over 1000 m³	8	16.32
	No information	17	34.70
Reef Purpose	Conservation and production	25	43.86
	Diving tourism	10	17.54
	Scientific research	22	38.60
Ministry Coordination	Reported	11	22.45
	Not available	38	77.55
Monitoring	Reported	40	81.63
	Not available	9	18.37
Monitoring Period	<12 months	8	16.33
	≥12 months	26	53.06
	Not available	15	30.61
Reef Stability	Reported	31	63.27
	Not available	18	36.73

The distribution of publication types shows that research articles constitute the highest share, followed by master's theses while doctoral theses remain less common. Geographically, AR applications are heavily concentrated in the Aegean Region. Marmara, Mediterranean, and Black Sea regions hosting significantly fewer studies. The most commonly used reef shape is cubic modules. In terms of material, concrete is overwhelmingly dominant, with sunken vessels/aircraft and steel/iron being other notable materials. Reefs are predominantly deployed at mid-depths of 15-30 meters, with an average depth of 20.50 meters. The most frequent reef volume range is 100 m³-1000 m³, yet a significant data gap exists, as 34.70% of studies lack information on total reef volume or the surface areas are given in km². The purpose of "protection and production" is more prevalent in AR studies, followed by scientific research purpose while dive tourism is a less common objective. A notable majority of studies (77.55%) lack or do not report central ministry coordination, indicating that many projects are conducted through local or institutional initiatives without centralized planning or documentation. Although monitoring activity is reported in a relatively high proportion of ARs (81.63%), monitoring duration is generally mid-term, and long-term monitoring is rare. Reef stability is confirmed in many of the ARs (63.27%).

According to Table 4, the dominant fish species observed around ARs were *Chromis chromis*, followed by *Diplodus vulgaris* and *Boops boops*. Other frequently encountered species were *Diplodus annularis*, *Spicara smaris* and *Coris julis*. However, 15.62% of ARs provided no information on species composition.

Table 4. Themes related to ecological characteristics

Ecological Characteristics		N	%
Dominant species	*Chromis chromis*	13	13.54
	Diplodus vulgaris	12	12.50
	Boops boops	8	8.33
	Diplodus annularis	7	7.29
	Spicara smaris	5	5.20
	Coris julis	5	5.20
	Oblada melanura	4	4.16
	Serranus cabrilla	3	3.12
	Scorpaena scrofa	3	3.12
	Sciaena umbra	2	2.08
	Serranus scriba	2	2.08
	Labrus spp.	2	2.08
	Mullus barbatus	2	2.08
	Other	13	13.54
	Not available	15	15.62
Increase in number of species	Reported	18	36.73
	Not available	31	63.27
Increase in individual abundance	Reported	19	38.78
	Not available	30	61.22

An increase in species number at the AR site was reported in 36.73% (18 AR sites) of the cases. Conversely, in the majority of AR sites (63.27%), no such increase was observed or no data were available. An increase in individual abundance following reef deployment was reported in 19 AR sites. However, in 30 AR sites, no significant increase was observed or measured.

Table 5 shows that the most commonly used data collection method in AR studies is visual census/observation which forms the foundation of field studies as a direct underwater observation technique. Underwater photography/videography also holds a significant place as a tool for visual documentation and supplementary data collection. Survey and interview methods were used almost equally and at lower rates, typically preferred for socio-economic assessments or studies based on fishers' knowledge. Active fishing methods such as gillnets and angling were relatively less preferred. The high proportion of the "Other" category (13.95%) in Table 5 indicates the use of various and non-standard data collection methods.

Table 5. Themes related to methodological information

Methodological Information		N	%
Data collection method	Visual census/observation	35	40.70
	Underwater photography-video recording	12	13.95
	Survey/Questionnaire	7	8.14
	Interview	6	6.98
	Gillnet	5	5.81
	Fishing rod	4	4.65
	Sample scraping	3	3.49
	Acoustic telemetry	2	2.33
	Other	12	13.95
Types of analysis/tests	Bray-Curtis similarity index	16	13.79
	ANOVA	13	11.21
	Mann-Whitney U test	11	9.48
	Shannon-Wiener diversity index	9	7.76
	Descriptive statistics	7	6.03
	Kruskal-Wallis test	7	6.03
	No statistical analysis	7	6.03
	n-MDS (Multidimensional scaling)	5	4.31
	t-test	5	4.31
	Jaccard index	5	4.31
	Chi-square test	3	2.59
	Correlation tests	3	2.59
	SIMPER analysis	3	2.59
	Probit model	2	1.72
	Tobit regression	2	1.72
	Other	18	15.52

The statistical and ecological analysis methods used in the studies show a wide range of approaches. The most common methods were the Bray-Curtis similarity index and ANOVA, indicating that researchers frequently focused on comparing community structures and testing differences between groups. The frequent use of the Shannon-Wiener diversity index further emphasizes the importance placed on assessing biodiversity and species composition in artificial reef studies. Non-parametric tests such as the Mann-Whitney U test and the Kruskal-Wallis test were also commonly applied, reflecting the non-normal distribution often encountered in ecological count data. A notable portion of studies (15.52%) employed methods categorized as “Other,” which includes techniques such as Bayesian regression, correspondence analysis, and economic parameter calculations. Additionally, 6.03% of studies reported using no statistical analysis.

Table 6 shows that the majority of studies contained ecological findings. Socio-economic findings were reported less frequently. Problems during the implementation of ARs were identified in 69.39% of the AR sites. Majority in the AR sites in the reviewed studies contained at least one recommendation related to the findings. AR performance scores of all indicators for 47 reefs are shown in Table 7.

Table 6. Themes related to research findings

Research Findings		N	%
Ecological findings	Reported	44	89.80
	Not available	5	10.20
Socio-economic findings	Reported	8	16.33
	Not available	41	83.67
Problems	Reported	34	69.39
	Not available	15	30.61
Recommendations	Reported	43	87.76
	Not available	6	12.24

Table 7. Statistics regarding AR performance scores in 47 reefs

AR Performance Indicators	N	Min.	Max.	$\bar{X}$	SD
Stability	47	0	1	0.77	0.41
Pre-deployment Monitoring	47	0	1	0.21	0.38
Post-deployment Monitoring	47	0	1	0.72	0.34
Management Objective	47	0	1	0.85	0.34
Positive Ecological Outcome	47	0	1	0.89	0.31
Positive Socioeconomic Outcome	47	0	1	0.17	0.37
Total Observation/Sampling	47	0	1	0.40	0.32
Cost Reporting	47	0	1	0.04	0.2
Overall Performance Score	**47**	**2**	**6.5**	**4.07**	**1.02**

The mean overall performance score for all studied ARs was 4.07±1.02. This indicates a moderate level of overall performance across the dataset. Of the 47 reefs evaluated, 21 scored above this mean. The relatively moderate standard deviation suggests some variability among projects, with scores ranging from a minimum of 2 to a maximum of 6.5. Among the individual performance indicators, Positive-Ecological Outcome received the highest mean score (0.89±0.31). In contrast, the lowest mean score was observed for Cost Reporting (0.04±0.20). Similarly, Positive-Socioeconomic Outcome scored low (0.17±0.37). The indicator Total Observation/Sampling also showed a moderate mean score (0.40±0.32). Notably, Post-deployment Monitoring scored relatively high (0.72±0.34), whereas Pre-deployment Monitoring was very low (0.21±0.38). High standard deviations were found across indicators such as Stability (0.41) and Pre-deployment Monitoring (0.38).

DISCUSSION

This meta-synthesis study provides the first comprehensive national synthesis that evaluates the current state of AR research in Türkiye in comparison with the international literature. The findings revealed that AR applications in Türkiye are largely concentrated in the Aegean Region, predominantly using concrete cubic modules at mid-depths (15-30 m) for protection and production purposes. Modular concrete units such as cubes or hollow blocks offer rapid and standardised production, a long service life, ease of transport and installation, and enhanced structural stability under wave and current forces (Seaman, 2000). They are frequently used because they also increase habitat complexity by providing internal voids, surface heterogeneity, and flow shelters, thereby encouraging the settlement and sheltering of marine organisms (Pickering and Whitmarsh, 1997). Within the Turkish context, the widespread use of modular concrete units (e.g. cubic and pentagonal designs), particularly in coastal and mid-depth environments, appears to be closely linked to practical considerations such as local production capacity, cost efficiency, structural stability, and the logistical feasibility of deployment and monitoring.

The results also indicate that AR studies in Türkiye are still limited (Savut, 2013) to local initiatives and academic projects, rather than being part of a standardized planning and implementation strategy at a regional level. Indeed, the fact that ministry coordination was not reported in 77.55% of the studies points to projects progressing in a fragmented, uncoordinated structure lacking an institutional framework, making monitoring difficult (Lök et al., 2022). International experiences show that AR projects in pioneering countries like Japan and the USA are supported by technical standards, long-term monitoring protocols, and centralized databases (Fabi et al., 2015), while such a level of institutionalization has not yet been achieved in Türkiye.

In summary, AR studies in Türkiye are notably concentrated in the Aegean Sea. All AR sites combined other than top nine AR sites account for 24.48%, suggesting that while ARs and other artificial marine structures are geographically widespread, empirical research remains heavily concentrated in a limited number of recurring locations. This spatial concentration may partly reflect the historical development of AR research in Turkey, which was initiated by the Faculty of Fisheries at Ege University in the early 1990s. Given the logistical demands of long-term monitoring and the constraints imposed by limited financial resources over extended periods, research efforts may have tended to focus on sites located closer to primary research institutions, where repeated monitoring was more feasible. While the monitoring rate is relatively high, major shortcomings include the lack of central coordination, significant data gaps in volume and stability reporting, limited long-term monitoring, and a scarcity of deep-water applications. Standardization of data reporting appears crucial for the field's development.

The study has found that ARs did not consistently lead to an increase in species richness, with a positive response documented in only a minority of ARs. These results suggest that the capacity of ARs to enhance fish stocks can vary across cases and time scales, with effectiveness likely influenced by project-specific and environmental factors. In this context, the limited availability of baseline information—most notably the fact that only 9 of 49 studies (18%) incorporated a defined pre-deployment monitoring period—may help explain the observed variability in artificial reef outcomes, reflecting methodological constraints similar to those highlighted by Paxton et al. (2020) regarding study design, baseline conditions, and monitoring duration.

Ecological findings confirmed that ARs serve as important attraction centers and habitats for certain species (particularly for *Chromis chromis* and *Diplodus vulgaris*), but also showed that fundamental objectives such as increases in biomass and species diversity were reported in only about 36-38% of the AR sites in reviewed studies. This result demonstrates that the ecological performance of ARs is not automatic and varies depending on factors such as site selection, design, monitoring duration, and methodology (Bohnsack, 1989). Furthermore, the failure to report basic ecological data like species composition in 14.56% of AR sites expose data quality and transparency issues in the field. International meta-analyses similarly emphasize that the effects of ARs on fish communities are project-specific and there is no universal guarantee of success (Paxton et al., 2020).

Majority of the studies presented certain ecological results which indicate that AR have a high observable impact on the ecosystem. It can also be stated that the studies without ecological findings were primarily pilot or socio-economic research. On contrary, AR studies lack of socio-economic results which suggests that these studies focused more on the ecological dimension, while socio-economic impacts were less investigated. Also, the frequent encountering of significant obstacles or adverse situations in the implementation of AR projects provides important insights for future studies and projects. This high rate of problem identification reveals that the implementation of AR projects needs better structuring from technical, social, and administrative perspectives. However, since this is a relatively new field of study in Türkiye, it is expected that these problems related to AR will be partially resolved over time. Finally, reported recommendations show that researchers not only identify problems but also offer solution proposals for implementati

Methodologically, while a large portion of the research relied on observer-dependent and non-standardized methods such as visual census, underwater imaging, and interviews or surveys. Quantitative fisheries data collection methods such as gillnet and fishing rods were less preferred. This distribution shows that AR research largely relies on direct observation and visual documentation, while the collection of quantitative fisheries data remains more limited.

In statistical analyses, while commonly used methods such as ANOVA and the Bray-Curtis similarity index indicate a focus on comparing communities and testing differences, the frequent application of the Shannon-Wiener diversity index underscores an interest in biodiversity assessment. However, the moderate to low use of more advanced community ecology tools such as MDS/nMDS and the Jaccard index alongside the limited employment of long-term population modeling, suggests that many studies remain short-term and predominantly descriptive in nature. More specialized community ecology tools including MDS/nMDS and the Jaccard index, were used at moderate frequencies, suggesting attention to multivariate patterns and presence-absence data.

This methodological tendency limits the ability to capture complex ecological interactions and population dynamics over time. As Bortone (2011a) emphasizes, for artificial reefs to serve as effective tools in fisheries management, the generation of consistent, quantitative, and managerially relevant data is essential. The current methodological diversity and reporting inconsistencies observed in Türkiye's AR studies thus represent a barrier to achieving this objective. Other statistical analysis methods highlight the diversity and specialization of analytical approaches within the field. Finally, AR studies lacking reported statistics may indicate a descriptive, qualitative or methodologically limited focus in some research.

The analysis reveals a clear hierarchy in the reporting quality and focus of AR projects. This reflects a strong focus on and reporting of ecological benefits. This hierarchy is most evident at the lower end of the scoring spectrum. This indicates that economic transparency and cost-related documentation are largely absent or poorly reported. However, modern AR projects are increasingly planned as multifunctional structures aimed at achieving socio-economic sustainability alongside ecological restoration (Spagnolo and Ferrà, 2025).

Similarly, Positive-Socioeconomic Outcome scored low. This suggests that socioeconomic aspects are significantly underreported or underrepresented compared to ecological outcomes. This situation highlights that the impacts of ARs on the local economy, fisheries income, and tourism are still insufficiently investigated and reported (Tunca et al., 2022). The data further shows inconsistent rigor in methodological reporting. This implies that sampling effort and observational adequacy vary considerably, with many studies likely having limited or unreported monitoring intensity. A critical finding is the stark contrast between monitoring phases. This highlights a common imbalance where baseline assessments are often overlooked. The performance scores for Stability and Pre-deployment Monitoring exhibited considerable variability due to higher standard deviations. This points to substantial heterogeneity in how AR projects are planned, implemented, and reported, which may reflect differences in regional practices, resources or methodological rigor. Overall, the results point to a lack of standardization in the field.

Bohnsack and Sutherland (1985) reviewed AR research up to 1984, and Bortone (2006) expanded this review by summarizing research trends and the research area's general state. Both reviews concluded that ARs were not sufficiently utilized in fisheries management—a situation that persisted despite numerous studies presented at international conferences. Bortone (2011a) argued that even when ARs were used in a fisheries management context, this often occurred as a byproduct or indirect effect of planned reef deployments rather than as the result of clear management objectives. Bortone (2011b) further emphasized that the existing knowledge base on ARs was inadequate to provide fisheries managers with the specific information they required for effective implementation. For ARs to play a meaningful role in management, a sufficient level of predictive certainty regarding their positive impact on fisheries is essential. While skepticism, unfamiliarity, and the perception of ARs as an untested alternative contribute to their underuse, the most critical barrier remains the lack of sufficient and specific data to verify their effectiveness (Bortone, 2011a). As highlighted in a survey by Steimle and Meier (1997), fisheries science must provide managers with information at various levels to support the development of effective reefs. Therefore, greater effort is needed from AR researchers to generate consistent, convincing data that can promote ARs as a credible management option.

In this respect, more comprehensive and standardized project documentation—particularly with regard to clearly defined objectives, baseline monitoring prior to deployment, and longer-term post-deployment observations—may be useful for more clearly capturing the tangible outcomes of AR projects and for improving the interpretability of reported results.

CONCLUSION

This research constitutes the first national synthesis study to comprehensively examine AR studies in Türkiye which employs meta-synthesis and AR performance scores. It has systematically assessed the current state of AR research in Türkiye, revealing the main strengths, deficiencies, and priority areas for improvement. The results show that despite the potential ecological benefits of ARs, their effectiveness is limited due to coordination deficiencies in implementation processes, cost reporting, short monitoring durations, methodological inconsistencies, and insufficient socio-economic assessments. However, our AR performance assessment approach does not provide an absolute qualitative assessment, but rather reflects the interpretations of different authors based on the data provided by the selected studies. The following recommendations are presented for developing more effective and sustainable AR projects in the future:

1. The effective functioning of the Artificial Reef Scientific and Technical Advisory Board should be ensured, and standard project monitoring and database protocols at the national level should be developed. Training specialized personnel on ARs within TAGEM and institutionalizing the existing knowledge base is important.
2. Minimum 3-5-year monitoring periods should be mandated in projects, and socio-economic impacts on fishery yields, dive tourism, and the local economy should be regularly evaluated alongside ecological parameters.
3. Researchers should report statistical analysis results (mean, standard deviation, sample size, test statistics, and p-values) completely and pay attention to the use of control areas. Methods that will increase quantitative data production should be encouraged.
4. AR projects should be designed to consider multiple objectives such as fisheries management, habitat restoration, coastal protection, and ecotourism, taking into account local hydrodynamic conditions, target species, and ecosystem needs.
5. An inventory of ARs implemented to date should be compiled, stable ones should be marked on nautical charts, and structures posing risks should be included in rehabilitation programs. ARs, especially in the Mediterranean and Aegean, could also be used as observation stations for monitoring invasive species.
6. Fishermen's cooperatives, local governments, non-governmental organizations, and relevant sector representatives should be actively involved in project planning and monitoring processes, and potential conflicts should be managed proactively.

In conclusion, ARs hold significant potential as a tool for sustainably managing Türkiye's marine resources and coastal ecosystems. However, realizing this potential fully depends on integrated management strategies implemented based on scientific planning, institutional cooperation, transparent data sharing, and a long-term perspective.

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AUTHOR CONTRIBUTIONS

All authors contributed to the conceptualization and design of the study. The manuscript was written and revised by the listed authors, all of whom have read and approved the final version.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest or competing interests.

ETHICS APPROVAL

No specific ethical approval was necessary for the study.

DECLARATION OF AI USE

We have not used AI-assisted technologies in creating this article.

DATA AVAILABILITY

Any requests or questions regarding data, the corresponding author should be contacted.

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Appendix 1. Complete table of the references correspond to ARs used in this study.

No	ARs	References
1	Edremit Bay (Altınoluk included)	Tunca (2011), Savut (2013), Tunca et al. (2013), Pelister (2014), Tunca et al. (2014), Özgül (2016), Tunca et al. (2016), Duman (2017), Özgül et al. (2019), Zengin (2024)
2	Ürkmez-Gümüldür	Gül et al. (2006), Çakaloz (2007), Ulaş et al. (2007), Gül (2008), Duman (2009), Duman (2017), Lök et al. (2008)
3	Karaburun (Büyükada & Küçükada included)	Şensurat-Genç et al. (2021), Şensurat-Genç (2022), Şensurat-Genç et al. (2022a), Şensurat-Genç et al. (2022b)
4	Hekimadası	Lök (1995), Gül (2001), Dayı (2001), Lök and Gül (2005)
5	Erdek Ocaklar / Erdek Bay	Acarlı and Ayaz (2015), Acarlı and Kale (2020a), Acarlı and Kale (2020b)
6	İstanbul Artificial Reef Project	Gül (2023), Gül and Ünsal (2024)
7	Kuşadası Bay (Pamucak)	Kemer (2022), Ulaş et al. (2023)
8	TCSG-132 Shipwreck	Kocabaş and Acarlı (2019), Acarlı et al. (2020)
9	Çeşme-Dalyanköy	Dayı (2001), Lök et al. (2008)
10	Urla-İskele Island	Ulaş (2000)
11	Gökçeada Underwater Park	Söylemez (2003)
12	Sinop Inner Harbor	Erdem (2006)
13	Çanakkale Underwater and Search & Rescue Sports Club Underwater Station	Özalp (2009)
14	Bodrum Karaada	Cerim (2011)
15	Adana Yumurtalık	Duman (2017)
16	İzmir Bay Urla Coast	Köken (2017)
17	Antalya Konyaaltı	Yılmaz and Sarıgöl (2018)
18	Ordu Ünye	Altaş (2019)
19	Ordu Mersin Village	Altaş (2019)
20	İskenderun Bay	Demirhan et al. (2020)
21	Mersin Silifke Akkum	Hamal (2025)