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REVIEW

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EFFECTS OF ARTIFICIAL BEACH NOURISHMENT ON WATER QUALITY AND MARINE BIOTA: A CRITICAL REVIEW

Efeitos das obras de engorda artificial de praias na qualidade da água e na biota marinha: Uma revisão crítica

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ABSTRACT

The aim of this paper is to provide an overview of the main effects of beach nourishment on water quality and marine biota through a critical review of the literature, considering the main scientific publications of the last twenty-five years. In the research conducted, artificial beach nourishment has proven to be an efficient means of combating the process of coastal erosion, and most of this research has focused on beaches on the European continent and in the USA. Following the completion of the fattening works, the main impacts observed were increased water turbidity, the presence of bacteria indicative of fecal contamination in the sediment of the fattening area, changes in the composition of the benthic community and the disappearance of *Posidonia oceanica* meadows. Most of these effects were temporary and some of them had a recovery time of up to four years. Finally, it is suggested to improve monitoring programs for the impacts of artificial beach fattening, as the lack of management and planning by the parties involved in fattening works may contribute to increase these impacts on the marine ecosystem.

Keywords: Dredging, environmental impact, beach fattening work.

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RESUMO

O presente trabalho tem como objetivo apresentar, por meio de uma revisão crítica da literatura, um panorama dos principais efeitos das obras da engorda de praias na qualidade da água e na biota marinha, considerando as principais publicações científicas dos últimos vinte e cinco anos. No levantamento realizado, a engorda artificial de praia tem se mostrado eficiente no combate ao processo de erosão costeira, e a maioria dessas pesquisas se concentraram em praias do continente europeu e nos EUA. Após a conclusão das obras da engorda, os principais efeitos observados foram elevação da turbidez da água, presença de bactérias indicadoras de contaminação fecal no sedimento da área da engorda, alterações na composição da comunidade bentônica e o desaparecimento dos prados de Posidonia oceanica. *A maioria desses efeitos tiveram magnitude de impacto temporária e alguns deles apresentaram tempo de recuperação de até quatro anos. Por último, sugere-se a melhoria dos programas de monitoramento dos efeitos da engorda artificial de praia, considerando que a falta de gestão e planejamento entre as partes interessadas nas obras de engorda podem contribuir para intensificar esses efeitos no ecossistema marinho.*

Palavras-chave: *Dragagem, impacto ambiental, obra de engorda de praia.*

INTRODUCTION

Coastal erosion is mainly responsible for the loss of coastal sediments in different regions of the world and has had a negative impact on the retreat of the coastline and the increase in flooding, which has caused damage to socio-economic activities in the coastal region (Castelle *et al*., 2009). Some measures have been taken to mitigate or reverse the advance of coastal erosion, such as beach nourishment, where sediments from a borrow area are redeposited onto the eroding coastal surface (Crowe *et al*., 2016). However, these works can have various impacts on the marine ecosystem, such as changes in water quality, changes in biota, sediment characteristics and beach morphology (Roman-Sierra *et al*., 2011; Crowe *et al*., 2016; Colosio *et al*., 2007). However, there are few studies that have assessed the impact of this type of development on the marine ecosystem, considering the large number of artificial beach nourishment projects being undertaken around the world.

Although these impacts are often overlooked or underestimated (Saengsupavanich *et al*., 2023), it is important to know the effects of beach nourishment on the marine ecosystem because there are activities associated with these works, such as sediment dredging, which, if not well planned and monitored, can affect the dynamics of waves and currents and even cause the loss of species composition of the benthic community (Thompson *et al*., 2021).

Against this background, the aim of this study is to provide an overview of the main impacts of beach nourishment on water quality and marine biota through a critical review of the literature, taking into account the main scientific publications of the last twenty-five years. This timeframe is justified considering that the number of beach nourishments has increased worldwide since the late 1990s (Saengsupavanich *et al*., 2023; Shih *et al*., 2011).

The aim was to find the answer to the research question through comprehensive and transparent research. For this purpose, a search was carried out in the Scopus and CAFe databases using the following keywords in conjunction with the Boolean operators (AND and OR): *"beach nourishment", "dredging", "sand by-pass", "renourishment", "beach restoration", "beach fill", "coastal nourishment", "impacts of dredging", "environmental impact", "environmental effects", "borrow sites", "beach erosion", "soft structures", "water quality", "seawater quality",* *"physicochemical parameters" and "monitoring".*

This article is divided into three specific topics. First, there is a brief overview of artificial beach nourishment and the dredging process. This is followed by a bibliographic review of selected studies on the effects of beach nourishment and discussions of these effects on water quality and marine biota. Finally, the concluding reflections summarize the main findings and highlight the importance of good management and planning in beach nourishment programs to contribute to the environmental sustainability of these projects.

ARTIFICIAL BEACH NOURISHMENT AND THE DREDGING PROCESS

Artificial beach nourishment consists of widening the beach strip by transferring a large amount of sediment from a borrow area into the eroded coastal zone, usually with the aim of combating coastal erosion (Crowe *et al*., 2016). These works protect coastal infrastructure against storms and sea level rise. Moreover, nourished beaches can recover quickly after storm surges, as much of the sand that has been transferred to the sea can form barriers that help to break the waves during storms and return to the beach during calm periods (Saengsupavanich *et al*., 2023). These works protect an area that might have been flooded if this type of intervention had not been carried out (Alves, 2021).

Some studies indicate that beach nourishment is beneficial to the protection of the coastal zone (Chiva *et al*., 2018; Ariffin *et al*., 2020), as artificial nourishment is an acceptable method of beach protection and is used worldwide to combat sediment depletion. Bitan and Zviely (2020) consider beach nourishment to be an ecologically and economically viable solution compared to structures such as dykes, revetments, breakwaters and isolated spurs. However, most of the work on beach nourishment focuses more on the properties and availability of the sediment than on the impact on the marine ecosystem (Saengsupavanich *et al*., 2023).

The first and probably most important step in beach nourishment is the definition of the deposit, which must have a sediment compatible with the original (Oliveira; Muehe, 2013; Medeiros *et al*., 2014). More than 95% of the sediment used for artificial beach nourishment comes from marine sediment sources (Dean, 2002 *apud* Medeiros *et al*., 2014). These materials are removed from the seabed by dredging. This is a hydraulic method (Luo *et al*., 2016) that uses dredges to remove or extract sediments from the bottom or rocks at the bottom of rivers, lakes, seas and other bodies of water. This method uses boats or floating platforms equipped with the necessary equipment (Alves, 2021).

In addition to the hydraulic method, other methods of artificial beach replenishment can also be used, such as the mechanical method using trucks or conveyor belts and the placement of artificial sediments (Medeiros *et al*., 2014; Luo *et al*., 2016). Dredging is typically used as basic operations to maintain navigation channels and remove contaminated sediments from aquatic ecosystems (Monte *et al*., 2019), but in beach nourishment works, the dredging process "involves removing beach-compatible material from a 'borrow area' and placing it on the eroding coastal surface to replace lost sand and augment littoral sediments" (Crowe *et al*., p. 875, 2016). The removal of sediments for beach nourishment has a negative impact on the seabed, particularly on benthic communities, both at the dredging site and in the surrounding area (Nonnis *et al*., 2002).

Dredging is a means of anthropogenic disturbance of coastal habitats and can profoundly affect the water quality of these ecosystems (Seoul Sangita *et al*., 2014) due to the increase in suspended sediments and the release of pollutants (Hiranandani, 2014; Seiyaboh *et al*., 2013), such as polycyclic aromatic hydrocarbons (PAHs) (Vagge *et al*., 2018) and heavy metals (Seiyaboh *et al*., 2013). Dredging of marine sediments increases the turbidity level in the water column (Ray *et al*., 2002), which changes the light intensity in the benthic region, leading to a decrease in the availability of dissolved oxygen (Jones *et al*., 2015) and a reduction in the abundance of benthic fauna (Menn *et al*., 2003). There are also changes in the physical environment, such as changes in bathymetry, current velocity and wave conditions (Wasim; Nine, 2017).

It is hoped that knowledge of these impacts will contribute to the development of new dredging techniques to reduce or minimize the environmental changes caused by these activities in artificial beach nourishment, as this process has already been shown in the literature to cause various changes in the marine ecosystem (Wasserman *et al*., 2016).

The first artificial beach nourishment projects in North America were carried out in California in 1919 (Manzanera *et al*., 2014) and off the coast of Coney Island and Brighton Beach in New York in 1923 (Silva; Lins-de-Barros, 2021). In Europe, this happened a little later, around 1950 (Manzanera *et al*., 2014). Currently, this type of intervention is carried out in countries such as Australia, France, Denmark, the United Kingdom, Germany, the Netherlands, Italy, Portugal, Japan, Korea, China, Vietnam, Malaysia and Sri Lanka (Saengsupavanich *et al*., 2023). Until 2014, the Netherlands was the country with the highest average sediment volume per fattening project, with around 733,000 m^3 of sediment deposited along its coast, making it the country that had carried out the most beach fattening projects up to that year (Luo *et al*., 2016). In the USA, this figure was around 327,000 m^3 for the same period (Luo *et al*., 2016).

In Brazil, the first beach nourishment works were carried out in the 1970s at Copacabana Beach in Rio de Janeiro and Curva da Jurema Beach in Espírito Santo. Leblon-Ipanema Beach underwent widening of the sand strip in 1992, followed by Praia do Balneário Piçarras in Santa Catarina, with its first project in 1998. Table 1 shows all Brazilian beaches that have been artificially nourished since the 1970s.

Santa Catarina and Espírito Santo are the Brazilian states with the highest number of artificial beach nourishment projects, and several more sand widening projects are planned for the coming years (Silva, 2022). Currently, the nourishment of Matinhos Beach in Paraná is considered the largest in the country (Suzin, 2024). However, the municipality of Itapoá in Santa Catarina is planning to carry out one of the largest artificial beach nourishment projects in the world.

Of the nourishment projects listed in Table 1, six contain one or more scientific studies on the effects of artificial nourishment on the marine ecosystem. However, none of these studies investigated the effects of artificial beach nourishment on seawater quality, taking into account all the conditions and quality parameters defined in CONAMA Resolution 357 of 2005 for Class 1 saline waters (Brasil, 2005). Only the work of Alves (2021) carried out this assessment, but did not take into account all quality conditions and parameters, focusing only on the inorganic parameters defined in the aforementioned Resolution.

STUDIES ON THE EFFECTS OF ARTIFICIAL BEACH NOURISHMENT ON WATER QUALITY AND MARINE BIOTA

Of the 19 studies listed in Table 2, twelve were conducted in European countries, four in the USA, two in Australia and one in Asia. Of these, five studies investigated the effects of beach nourishment on water quality, 11 studies investigated the effects of beach nourishment on the benthic community, two studies investigated the effects on the marine angiosperm *Posidonia oceanica* and one study investigated the effects on coral reefs.

Table 1 – Brazilian beaches artificially fattened until 2023

Beach	**City**	**State**	**Year of work**	**Sediment replenishment**	**Study**
Copacabana	Rio de Janeiro	RJ	1970	Yes	ND
Curva da Jurema	Vitória	ES	1970	Yes	ND
Leblon-Ipanema	Rio de Janeiro	RJ	1992	Yes	ND
Praia de Piçarras	Balneário Piçarras	SC	1998	Yes	Almeida *et al.*, 2018
Arpoador	Rio de Janeiro	RJ	1999	ND	ND
Ponta das canas	Florianópolis	SC	1999	ND	ND
Camburi	Vitória	ES	1999	Yes	Prata, 2005
Iracema	Fortaleza	CE	2000	Yes	ND
Bugia	Conceição da Barra	ES	2010	No	ND
Ponta da praia	Santos	SP	2012	Yes	Italian, 2014
Candeias, Piedade e Barra de Jangada	Jaboatão dos Guararapes	PE	2013	Yes	Sena, 2018
Meireles	Fortaleza	CE	2019	No	Alves, 2021
Canasvieiras	Florianópolis	SC	2019	No	ND
Praia central	Balneário Camboriú	SC	2021	No	ND
Matinhos	Matinhos	PA	2022	No	ND
Ingleses	Florianópolis	SC	2022	No	ND
Meaípe	Guarapari	ES	2023	No	ND

Source: Written by the author. **Note:** ND = No data.

Table 2 – Literature review on the effects of beach nourishment on water quality and biota

References	Location	Year	Water quality variables, conditions and parameters analyzed	Magnitude of impact	Effects	Legal aspects
1.	Spain	2011	Turbidity, salinity, pH, dissolved oxygen, temperature and benthic community	Temporary	Temporary turbidity and variation in the composition of the benthic community	ND
2.	Australia	1999	Turbidity	Temporary	Temporary turbidity in the water column	ND
3.	Italy	2018	Turbidity, temperature, salinity, pH, dissolved oxygen, total nitrogen and total phosphorus.	Temporary	Variation in dissolved oxygen concentration and temporary turbidity in the water column	ND
4.	Spain	2018	Turbidity	Definitive	Increase in turbidity	ND
5.	USA	2013	Bacteria indicative of fecal contamination	Temporary	Sediment contamination in the fattening area	USEPA
6.	USA	2016	Benthic community	Temporary	Variation in species composition	ND
7.	Italy	2007	Benthic fauna	Temporary	Changes in benthic fauna	ND
8.	Netherlands	2012	Abundance of macroinvertebrates	Temporary	Changes in the composition of the benthic community	ND
9.	Germany	2003	Benthic infauna	Temporary	Reduction in the abundance of benthic macrofauna and fauna	ND
10.	Netherlands	2001	Disturbance to the benthic community	Temporary	Decrease in the abundance of the benthic community	ND
11.	Taiwan	2011	Benthic invertebrates	Temporary	Variation in the composition and number of individuals in the community	ND
12.	Italy	2018	Benthic fauna	Temporary	Changes in polychaete abundance and community structure	ND
13.	Spain	2015	*Posidonia oceanica*	Definitive	Disappearance of *Posidonia oceanica* meadows	ND
14.	Australia	2012	Benthic invertebrates	Temporary	Variation in the benthic invertebrate community	ND
15.	Italy	2009	Benthic assemblages	Temporary	Low species richness and diversity of macrobenthos assemblages	ND
16.	USA	2002	Benthic community	Temporary	Decrease in benthic infauna abundance, biomass and number of taxa	ND
17.	Spain	2014	*Posidonia oceanica*	Definitive	Burial of *Posidonia oceanica* caused by sedimentation	ND
18.	USA	2008	Coral reef community	Temporary	Change in the stress level of corals	ND
19.	Italy	2002	Benthic community	Temporary	Variation in community composition	ND

Source: Written by the author.
Note: ND = No data
References: 1 - Roman-Sierra *et al.* (2011); 2 - Black; Parry (1999); 3 - Danovaro *et al.* (2018); 4 - Chiva *et al.* (2018); 5 - Rippy *et al.* (2013); 6 - Crowe *et al.* (2016); 7 - Colosio *et al.* (2007); 8 - Leewis *et al.* (2012); 9 - Menn *et al.* (2003); 10 - Van Dalfsen; Essink (2001); 11 - Shih *et al.* (2011); 12 - Danovaro *et al.* (2018); 13 - Aragonés *et al.* (2015); 14 - Schlacher *et al.* (2012); 15 - La Porta *et al.* (2009); 16 - Ray *et al.* (2002); 17 - Manzanera *et al.* (2014); 18 - Fisher *et al.* (2008); 19 - Nonnis *et al.* (2002).

Effects of Artificial Beach Fattening on the quality of seawater

When analyzing the five studies on the impacts of beach nourishment on seawater quality (Roman-Sierra *et al*, 2011; Black; Parry, 1999; Danovaro *et al*, 2018; Chiva *et al*, 2018; Rippy *et al*, 2013), turbidity was the most frequently studied variable compared to others. This may be due to the importance of this parameter in water quality research, particularly in beach restoration projects where sediments are dredged, as it is an activity that creates sediment plumes that can be dispersed by the tides (Ray *et al.*, 2002).

Roman-Sierra *et al.* (2011) investigated the physical, chemical and biological changes in marine waters caused by dredging activities, in which a pre-operational campaign was carried out followed by seven other operational campaigns. Temporary turbidity was detected during the dredging operations, probably caused by the resuspension of sediments (Chiva *et al.*, 2018), with average values of 1.2 and 1.6 UNT (Nephelometric Turbidity Unit) at 7 and 8 meters depth, respectively, and 3.2 UNT at the surface. However, the turbidity gradually decreased and returned to normal conditions about 9 minutes later. The same result was observed in the study by Black; Parry (1999), conducted in southeast Australia, where 98% of the sediment in the plume was redeposited about 30 minutes after the dredging activity.

Danovaro *et al.* (2018) and Chiva *et al.* (2018) investigated turbidity episodes during and after beach nourishment works in Italy and Spain, respectively. Danovaro *et al.* (2018) found the highest turbidity value of 4.5 UNT during beach nourishment but did not report how long the aquatic ecosystem needed to return to normal conditions. Chiva *et al.* (2018) found that the permanent turbidity of the water after beach restoration was caused by the difference in the mineralogical and morphological composition of the sediments used for beach restoration compared to the original sediments (before nourishment).

Unlike turbidity, the parameters pH, dissolved oxygen and temperature were not significantly affected by the dredging work (Danovaro *et al.*, 2018; Roman-Sierra *et al.*, 2011). The pH remained practically constant throughout the water column during all operational campaigns, with average values of 8.2 and 8.3 in the dredging and dumping areas respectively (Roman-Sierra *et al.*, 2011). Danovaro *et al.* (2018) investigated the impacts of beach nourishment on the macrofauna of the Adriatic Sea in Italy and found similar pH values to the study by Roman-Sierra *et al.* (2011), with values between 8.2 and 8.6. pH values in this range have no negative effects on the biota and values above 8.7 may be related to high photosynthetic activity in the aquatic ecosystem (Pedrosa *et al.*, 2006).

The average dissolved oxygen concentrations show saturation values of about 111% in the dredging and dumping zones for all stations and the entire water column (Roman-Sierra *et al.*, 2011) and a supersaturation of 119.8% before beach nourishment (Danovaro *et al.*, 2018). However, in both studies, a progressive decrease in dissolved oxygen was observed as a function of depth in the dredging zone, which is considered normal as the concentration of dissolved oxygen in water bodies tends to decrease with increasing depth (Chiva *et al.*, 2018). The dissolved oxygen concentrations shown are related to the high photosynthetic activity, which directly contributes to the increase in dissolved oxygen concentration in the water, as this variable is essential for the metabolism of the aquatic ecosystem (Fiorucci; Benedetti Filho, 2005).

In terms of temperature and salinity, the study by Roman-Sierra *et al.* (2011) recorded a maximum temperature of 17.4°C in the dredging zone and 18.8°C in the dumping zone for all stations, while in the study by Danovaro *et al.* (2018), the temperature remained relatively homogeneous throughout the study area with an average value of 22.5 °C, as did the salinity with an average concentration of 35.5 ‰, which was close to the average concentration of 37.4 ‰ determined in the study by Roman-Sierra *et al.* (2011). The biota of the marine ecosystem reacts differently to temperature and salinity conditions and can undergo fluctuations in their composition, density and distribution (Oliveira, 2022; Sarmento, 2016). These fluctuations depend on the environmental conditions of the aquatic ecosystem in question (Ferreira, 2016; Pezzi *et al*., 2016). The studies by Roman-Sierra *et al*. (2011) and Danovaro *et al*. (2018) found temperature and salinity values within the typical values for each aquatic ecosystem studied (Ferreira, 2016).

Only the study by Danovaro *et al*. (2018) assessed the concentrations of nitrogen and total phosphorus in the water column. No concentrations of ammonia were detected, but an average concentration of nitrate of 15 μg L^{-1} and total nitrogen of 235 μg L^{-1} was found. Phosphates and total phosphorus were similar at all the stations studied, with average values of 9.5 μg L^{-1} and 112 μg L^{-1}, respectively. Although the authors did not provide an in-depth discussion of the relationship between nutrients and aquatic ecosystem dynamics, which is necessary to understand the functioning of marine trophic chains, the concentrations found in the aforementioned study show that these values do not present a risk of eutrophication in the water body studied (Dias da Cruz, 2016). All studies in Table 2 indicated that the sediment originated from the seabed and obtained from dredging operations, with the exception of the work by Danovaro *et al*. (2018), in which the origin of the sediment used for beach nourishment was not specified, and the study by Rippy *et al*. (2013), in which the sediment originated from the dredging of the Goat Canyon detention basin in California. In this last example, the dredged sediment contained bacteria of the genus *Enterococcus*, which are considered indicators of fecal contamination. The average *Enterococcus* concentration in the fattening area was 141 organisms per 100 ml sample, above the maximum level of 104 organisms per 100 ml allowed by the US Environmental Protection Agency (USEPA). However, this concentration decreased to values close to zero after the end of the fattening work (Rippy *et al*., 2013). The *Enterococcus* values found are clearly associated with the resuspension of sediment from the beach nourishment. The *Enterococcus* contamination originates from the influence of sediment from the Goat Canyon retention basin in California, which retains more than 30,500 m^3 of sediment annually (Rippy *et al*., 2013), in addition to other sources such as sewage discharges, bird droppings, and beach litter (Brooks *et al*., 2005).

With the exception of the study by Rippy *et al*. (2013), the other studies in Table 2 did not indicate whether the concentrations of the parameters determined in each study were consistent with water quality norms or laws and standards, and whether these values were consistent with the maximum values allowed for each water body studied, taking into account the legal aspects of each country.

The lack of information on marine water quality conditions and standards in scientific papers, as well as on the maximum allowable values for each parameter, makes it difficult to understand the dynamics between pollution load and ecosystem resilience and prevents a broader discussion on the potential toxic effects that certain compounds can cause in a water body when they are present in high concentrations in the water column.

Resolution No. 357 of 2005 of the National Environmental Council (CONAMA) divides water bodies into classes to ensure the quality required for their preponderant uses. Therefore, information on marine water quality conditions and standards are frequently found in Brazilian research. In contrast, in the United States and Europe, there is no specific standard for this purpose, but laws that regulate the consumption and management of water resources (Trindade; Hoornbeek, 2020; Schmidt; Ferreira, 2014).

In Europe, for example, the classification and categorization of water bodies is carried out according to the European Directive 2000/60, which states that a complete ecological analysis of aquatic ecosystems must be carried out for the classification of water bodies (Forgiarini *et al*., 2007) and not only isolated analyzes of physical, chemical and biological parameters. In the United States, water quality control criteria are set by the USEPA (Pessôa *et al*., 2015) and design criteria for beach nourishment must follow the Army Corps of Engineers Coastal Engineering Manual (Shih *et al.*, 2011).

Effects of Artificial Beach Nourishment on the biota of the marine ecosystem

Of the studies listed in Table 2, 14 of them investigated the effects of beach nourishment on the biota of the marine ecosystem. Most studies investigated the benthic community and reported changes in species composition and a decrease in community abundance (Crowe *et al.*, 2016; Colosio *et al.*, 2007; Leewis *et al.*, 2012; Menn *et al.*, 2003; Van Dalfsen; Essink, 2001; Shih *et al.*, 2011; Danovaro *et al.*, 2018; Schlacher *et al.*, 2012; La Porta *et al.*, 2009; Ray *et al.*, 2002; Nonnis *et al.*, 2002; Roman-Sierra *et al.*, 2011). Other researchers have investigated the effects of artificial beach fattening on marine flora (Aragonés *et al.*, 2015; Manzanera *et al.*, 2014) and coral reefs (Fisher *et al.*, 2008).

Beach nourishment has many effects on benthic invertebrates (Schlacher *et al.*, 2012; Shih *et al.*, 2011), such as ecological changes in the structure of the benthic fauna and a decline in the abundance of copepod crustaceans (Menn *et al.*, 2003). The colonization of opportunistic annelid species (*Capitella capitata, Magelona papillicornis, Scololepis squamata, Spio filicornis, Spiophanes bombyx*) was observed during artificial beach nourishment in the Netherlands, which represents an ecological response to anthropogenic interventions in the coastal environment (Van Dalfsen; Essink, 2001). However, opportunistic populations declined 8 months after the end of the work and full recovery of the benthic community took up to 4 years.

It is common for opportunistic species to appear during and/or after beach nourishment (Nonnis *et al.*, 2002). However, these species usually disappear again when the affected area is colonized. This can occur by immigration from the surrounding area, by fixation of larvae in the water column or by dispersal of species from areas that have not been altered, as well as by benthic organisms that can survive the dumping of marine sediments and contribute to the recovery of the local community (Van Dalfsen; Essink, 2001).

Beach nourishment alters the benthic community (Crowe *et al.*, 2016; Menn *et al.*, 2003; Van Dalfsen; Essink, 2001; Shih *et al.*, 2011; Schlacher *et al.*, 2012; Nonnis *et al.*, 2002; Roman-Sierra *et al.*, 2011) in terms of faunal density and number of species. However, in the study by Leewis *et al.* (2012), which investigated whether beach nourishment has a long-term impact on the abundance of macroinvertebrate species on the Dutch sandy coast, no negative effects were identified. The authors studied four species of macrofauna (*Scolelepis squamata, Haustorius arenarius, Bathyporeia sarsi and Eurydice pulchra*) and found no negative effects on the benthic fauna, with recovery in species diversity occurring one year after beach nourishment, and even earlier for the species *Scolelepis squamata*.

Some beach nourishment works have caused negative impact on marine flora, particularly on the marine angiosperm species *Posidonia oceanica*, which is endemic to the Mediterranean (Aragonés *et al.*, 2015; Manzanera *et al.*, 2014). Due to the excess sediments dumped on the beach, part of the *Posidonia oceanica* meadow was buried, leading to its death and consequently to an ecological imbalance in the marine ecosystem. In addition, climatic effects such as strong storms contributed to the transfer of sediments and thus to the burial of *Posidonia oceanica*.

With the exception of the studies by Manzanera *et al.* (2014) and Aragonés *et al.* (2015), which were conducted on the Catalan coast and in Benidorm (Spain), respectively, the impacts of beach nourishment on marine biota observed in the other studies in Table 2 were temporary and ecological stability was restored after the work was completed. Of all the studies presented, the maximum recovery time for biota was four years (Van Dalfsen; Essink, 2001) and the minimum time was one year (Leewis *et al.*, 2012). Other studies have shown different recovery times for the benthic community associated with the effects of beach nourishment, ranging from 1,5 (Roman-Sierra *et al.*, 2011) to 2.5 years (Ray *et al.*, 2002). In general, recovery is faster when the new sediments match the original ones (Schlacher *et al.*, 2012). On the other hand, recovery can be hindered if the added sediment differs significantly from the original beach sediments (Peterson *et al.*, 2006).

Some studies have shown that marine biota do not recover after artificial beach nourishment (Crowe *et al*., 2016; Colosio *et al*., 2007; Shih *et al*., 2011; Danovaro *et al*., 2018; Aragonés *et al*., 2015; Schlacher *et al*., 2012; Manzanera *et al*., 2014; Fisher *et al*., 2008; Nonnis *et al*., 2002; Rippy *et al*., 2013), which is a significant gap considering that such work can have negative impacts on marine ecosystems (Saengsupavanich *et al*., 2023). This scenario underscores the urgency of more detailed studies on the ecological impacts of these interventions and the time required for affected ecosystems to recover.

FINAL CONSIDERATIONS

The number of artificial beach nourishments designed to mitigate or reverse the effects of coastal erosion has steadily increased worldwide. However, almost all studies on the ecological impact of these works have focused on research on the European continent and in the USA. Only one study presented a legal instrument to regulate water pollutants, and the other studies did not report whether the concentrations of the parameters found in the individual studies comply with any norms or laws on saline water quality conditions and standards.

Dredging and beach nourishment cause impacts that extend beyond the area directly affected by the project. Among the physical effects observed in the water, increased turbidity is the most evident. Although the natural flora and fauna can recover after beach nourishment, permanent changes in their composition have been observed. Nevertheless, the benthic community has proven to be a good indicator for monitoring the effects of nourishment works on the biota of sandy beaches.

Although beach nourishment is effective against the process of coastal erosion, some authors believe that it should not be seen as a permanent solution to erosion. Although there is much published research addressing the effects of beach nourishment on the marine ecosystem, there is little information on how impacts and recovery vary along the coast. Consequently, many ecological questions about the impacts of beach nourishment remain unanswered. Although most of these impacts are temporary, monitoring programs for the impacts of artificial beach nourishment need to be monitored and improved, because in some cases there are failures in management and planning among stakeholders in nourishment works, which may contribute to the negative impacts of this activity on the marine ecosystem. In addition, the dynamics of the seas and coasts are of particular importance for each region where this type of intervention is carried out, which reinforces the need for such monitoring.

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