

Artificial wrecks: Unwanted consequences of the deliberate sinking of ships for recreational diving

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ABSTRACT. Artificial reefs are submerged human-made objects. In particular, the artificial wrecks are intentionally submerged obsolete ships. Once deployed, these wrecks are rapidly colonized by diverse benthic communities. Currently, this effect is positively valued by the recreational diving industry, which uses this colonization effect as one of the main arguments to promote the deployment of artificial wrecks. However, there is increasing evidence that artificial wrecks are not a substitute for natural reefs and may alter complex ecological processes such as food web structure and increase the likelihood of invasive species establishment and spread. Here, we discuss our main concerns related to the unintended socioecological consequences of the creation of artificial wrecks, problematizing the paradigm that this practice favours marine conservation. Although we recognize that artificial wrecks have positive economic, social and even some environmental outcomes, we argue that the benefits are often usufructed by only a portion of society and that this practice requires a broader discussion. Finally, we also discuss the management implications of these concerns and propose alternatives to encourage recreational diving through the adoption of more environmentally sustainable and socially participative approaches. Hopefully, this will lead to better and more consensual practices for the management of coastal areas.

[Keywords: adaptive ecosystem management, artificial reefs; ship recycling, ship scuttling, invasive species, shipwrecks]

RESUMEN. Pechos artificiales: Consecuencias no deseadas del hundimiento deliberado de buques para el buceo recreativo. Los arrecifes artificiales son estructuras sumergidas de origen antrópico. En particular, los arrecifes artificiales a partir del hundimiento intencional de buques obsoletos se utilizan a menudo para crear parques y fomentar el turismo subacuático. Una vez hundidos, una diversa comunidad de organismos bentónicos coloniza rápidamente estos pechos artificiales. La industria del buceo recreativo valora esto de forma positiva, y es su principal argumento para promover los hundimientos. Sin embargo, existe una cantidad creciente de evidencias que muestran que los pechos artificiales no sustituyen los arrecifes naturales, y que, en cambio, pueden alterar procesos ecológicos complejos como la estructura de las tramas tróficas o incrementar el riesgo de establecimiento y dispersión de especies marinas invasoras. En este artículo discutimos diversas inquietudes sobre las consecuencias socioecológicas no deseadas de crear arrecifes artificiales mediante el hundimiento intencional de buques obsoletos, y problematizamos el paradigma de que esta práctica favorece la conservación marina. Aunque reconocemos que este tipo de arrecifes artificiales tienen beneficios económicos e, incluso, algunos efectos positivos en el ambiente, argumentamos que estos beneficios suelen alcanzar solo a una porción de la sociedad y que es una práctica que requiere ser discutida en un contexto más participativo. También discutimos aquí las implicancias para la gestión y proponemos ideas para fomentar el buceo recreativo mediante enfoques más sostenibles en términos ambientales. Esperamos aportar puntos de vista que conduzcan a avanzar en una gestión más integral y participativa de las áreas marino-costeras.

[Palabras clave: parques submarinos, buceo recreativo, hundimiento de buques, arrecifes artificiales, naufragios, desguace de buques]

INTRODUCTION

Artificial reefs are submerged human-made objects that can shift the structure, function or behaviour of organisms and biological communities (Tynyakov et al. 2017; Lima et al. 2019). As such, they are increasingly used, among other strategies, to alleviate the anthropogenic pressure on particularly vulnerable marine habitats, contributing to their conservation (Tynyakov et al. 2017). Among the various types of artificial reefs, intentionally submerged ships (hereafter artificial wrecks) are commonly used as recreational diving sites (Lima et al. 2019) and are especially useful to reduce the diving pressure on vulnerable natural or cultural sites (Firth et al. 2020; Ramm et al. 2021).

Post-deployment, artificial wrecks are rapidly colonized by a diverse community of marine invertebrates, algae and fishes, driven by the availability of large settlement surfaces, increased habitat complexity and the provision of refuge against predators (dos Santos et al. 2010; Dance et al. 2011; Genzano et al. 2018). The resultant increase in biomass and diversity, mainly observed in fish communities, is positively valued by recreational divers (Kirkbride-Smith et al. 2016; Lowry et al. 2017) and stands as one of the main arguments supporting the deliberate sinking of ships for the creation of artificial reefs. However, unlike other types of artificial reefs, the deployment of artificial wrecks might have other unintended consequences commonly overlooked (Heery et al. 2017).

Coastal environments are complex socioecosystems that contribute to human well-being in various ways (Noble et al. 2019). Thus, their effective management should encompass both human and environmental well-being to ensure sustainability (Bennett et al. 2019). In this context, we discuss our main concerns related to the unintended socioecological consequences of the creation of artificial wrecks, challenging the widely accepted paradigm that they enhance marine conservation. While acknowledging the sometimes positive economic, social and environmental outcomes linked to artificial wrecks, we argue that these benefits are often enjoyed by a portion of the society, despite their occurrence in public spaces, while potentially adversely affecting local communities through unintended consequences. Using examples mainly from Argentina, we highlight these concerns and discuss their management

implications, and propose alternatives to promote recreational diving through more sustainable and participative approaches.

REASONS BEHIND THE DELIBERATE SINKING OF SHIPS

As a means of disposing obsolete ships

Most commercial vessels retain a positive value at the end of their lifespan, which makes their deliberate sinking an economically inconvenient alternative for their final disposal (Devault et al. 2017). The profitability of commercial ship recycling is partly achieved by significantly low labour costs and minimal environmental, safety and health regulations in India, Pakistan, Bangladesh, China and Turkey, where the global scrapping market is focused (Hynes et al. 2004). However, this is not the case for seized, abandoned or non-commercial vessels, such as military and other state-owned ships. Instead, they are usually disposed of on land, piled up at port mooring sites or sunk to create artificial wrecks (Devault et al. 2017) (Figure 1a-c). Although more widespread in countries like the USA and Australia, the sinking of obsolete ships is a common practice around the world (Ilieva et al. 2019). A notable example in the Southwestern Atlantic is the recent sinking of a 266-meter-long aircraft carrier off the coast of Brazil (bit.ly/481SM4M). Originally built in 1950 as Foch for the French Navy, the vessel was later acquired by Brazil and renamed Sao Paulo. It was sold for scrapping in 2021 to the shipyard Sok Denizcilik, but Turkey later refused entry due to concerns over hazardous materials. Finally, the Brazilian Navy intentionally sank the ship to prevent further complications for the government. In Argentina, artificial wrecks most commonly result from the sinking of obsolete fishing vessels, either abandoned, seized or formally transferred by fishing companies, with 15 records from 1981 to the present (Castro et al. 2023) (Figure 2a). Some examples include the giant Khronometer, which was abandoned in Mar del Plata port following the dissolution of the Soviet Union. In 2014, it was sunk as part of the port consortium's initiative to recover operational space at the dock. Several other fishing vessels met the same fate in this location because of this project (Figure 2a). In the following year, the squid jigger vessel Hu Shun Yu 809 was apprehended for illegal fishing within the Argentinian Exclusive Economic Zone and subsequently confiscated

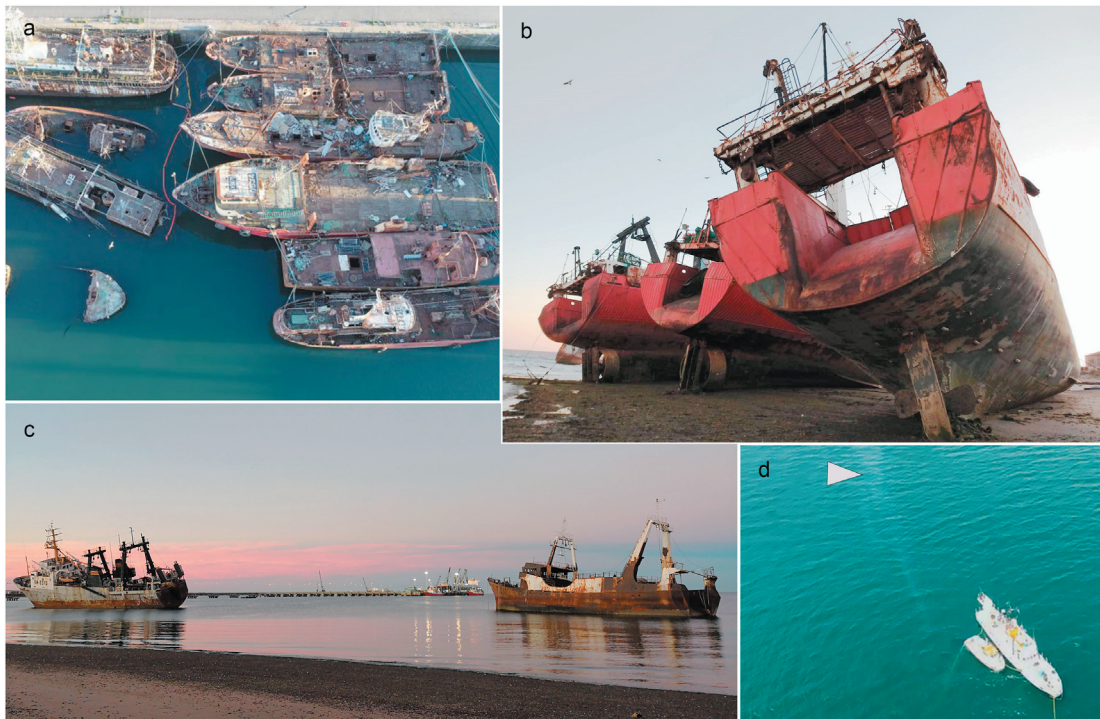


Figure 1. Obsolete ships in Argentina. a) Dron view of the port of Mar del Plata, Buenos Aires province, in 2019. b and c) Ships on land in the port area of Puerto Madryn, Patagonia. d) The maritime authority at the Hu Shun Yu 809 deployment site, examining the reasons why the oil plume (white arrow) could be seen emerging from the artificial wreck. Photo credits: a) Pablo Funes @dronmardelplata (a), Pablo Tavella (b), Alejandro Bortolus (c), lu17.com (d).

Figura 1. Barcos obsoletos en la Argentina. a) Vista aérea del puerto de Mar del Plata en 2019. b y c) Fotografías de barcos obsoletos confiscados o abandonados en el puerto de Puerto Madryn, Patagonia Argentina, d) La autoridad marítima en el sitio de hundimiento del Hu Shun Yu 809, examinando las causas por las que una gran mancha de aceite (ver flecha blanca) emergía del barco hundido. Créditos de las fotografías: Pablo Funes @dronmardelplata (a), Pablo Tavella (b), Alejandro Bortolus (c), lu17.com (d).

by the maritime authority (Prefectura Naval Argentina 2015). After its seizure, the ship was abandoned in Puerto Madryn port, located in northern Patagonia, causing operational disruptions and incurring costs for the private port administration. After more than three years of litigation, the government finally authorized the sinking of the vessel to prevent further complications (Figure 2b). In response, the port administration amended its legal framework to prohibit future moorings of confiscated vessels (APPM, Res 003/18). Another case, albeit resolved more quickly, involved the trawler *Urabain*, which caught fire in 2017 while docked at Puerto Madryn port. The ship was rendered inoperable by the fire, and in the absence of viable alternatives, the government authorized its sinking one year later (Chubut Government 2017) (Figure 2c). Altogether, these cases show how the deliberate sinking of abandoned or seized ships, which often occupy valuable port space, appears as the easiest option for their disposal (Sheehy and Vik 2010; Devault et al. 2017).

To attract recreational SCUBA divers

Once rare, the practice of recreational SCUBA diving has experienced rapid growth during the last decades (Hasler and Ott 2008). Shipwrecks offer attractive opportunities for recreational divers, which led to an increasing demand for wreck diving sites (Edney 2017) and, in turn, to the creation of artificial wrecks to enhance local recreational diving industries (Oh et al. 2008; Shani et al. 2012; Ha et al. 2020). For many recreational divers, artificial wrecks contribute to increasing the positive image of diving destinations and add extra value to their experiences (Stolk et al. 2005; Shani et al. 2012). In fact, their size is the primary factor influencing divers' preferences (Şensurat-Gençet et al. 2022).

The rise of recreational diving has escalated the pressure on natural marine habitats (Schleyer and Tomalin 2000; Polak and Shashar 2012), which can add thousands of dives per year. Sometimes, this pressure severely affects vulnerable aquatic ecosystems

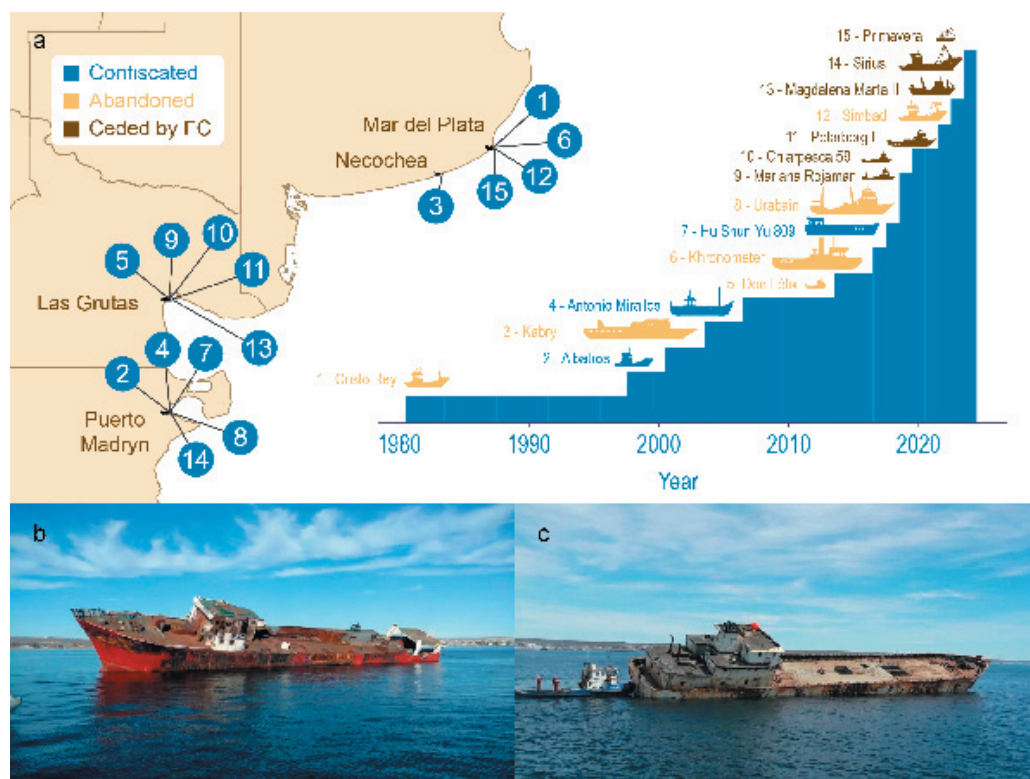


Figure 2. Intentional sinking of obsolete ships in Argentina. a) Number of sinking over time and their distribution along the coast. Color indicates the origin of the vessel (blue: confiscated; orange: abandoned; brown: formally ceded by a fishing company). b) The trawler Urabain, which caught fire while moored at the Puerto Madryn port. c) The squid jigger Hu Shun Yu 809, confiscated for illegal fishing. Photo credits: elobservadordelsur.com (b), elchubut.com (c).

Figura 2. Hundimientos intencionales de buques obsoletos en la Argentina. a) Número de hundimientos en función del tiempo y su distribución a lo largo de la costa. b) El barco de arrastre Urabain, que se incendió amarrado al muelle de Puerto Madryn. c) El barco potero Hu Shun Yu 809 confiscado por pesca ilegal. Créditos de las fotografías: elobservadordelsur.com (b), elchubut.com (c).

such as tropical coral reefs or cold-temperate rocky reefs (Hasler and Ott 2008; Bravo et al. 2015). In response, the deliberate sinking of ships is one of the multiple management strategies that have been proposed to mitigate the negative effects of recreational diving and fishing (Polak and Shashar 2012; Tynyakov et al. 2017; Higgins et al. 2022). The use of artificial wrecks can alleviate the pressure on particularly vulnerable sites and contribute to their conservation (Tynyakov et al. 2017). However, as with any other strategy, deliberate sinking ships is not a silver bullet and needs to be adapted to the socioeconomic context of each diving destination (Polak and Shashar 2012; Tynyakov et al. 2017). In recent years, this activity has grown exponentially in Argentina, mainly concentrated in three coastal locations that actively promote sub-aquatic ecotourism (Mar del Plata, Las Grutas and Puerto Madryn) (Figure 2a). Puerto Madryn is recognized as the national capital for diving and underwater activities. Recently, the provincial government announced plans

to sink six more ships to further promote this activity (bit.ly/47LXqFn). Even though some stakeholders claim that these wrecks are beneficial for the underwater environment, there is not enough evidence of such effects, and the creation of artificial wrecks may also produce unintended consequences.

UNINTENDED CONSEQUENCES OF ARTIFICIAL WRECKS

Chemical pollution

Prior to deliberately sinking a ship, all hazardous and toxic materials are required to be removed (Devault et al. 2017). This is usually a time-consuming and expensive task (Hynes et al. 2004). Pollutants such as fuel, oils, polychlorinated biphenyls, antifouling paints, asbestos and other hazardous materials can produce extremely negative impacts if not carefully removed before deliberate sinking (Amara et al. 2018). Wrecks can alter the structure and dynamics of benthic communities by

changing the physicochemical properties of the surrounding area (Heery et al. 2017; Van Landuyt et al. 2022). Metal wrecks can produce rapid species turnover in areas with limiting concentrations of iron (Kelly et al. 2012). In such areas, phase shifts were described in association with an increased amount of iron leaching from wrecks (Kelly et al. 2012; Work et al. 2018). In addition, ship hulls have historically been treated with antifouling paints to control biofouling accumulation. These include biocides such as copper (Cu), lead (Pb) or tributyltin (TBT) that are slowly released into the environment (Komyakova et al. 2022). Particularly, TBT is an organic tin compound that has been used since 1960 as a highly effective antifouling agent, known to cause deformities in oysters and imposex in sea snails (Bigatti et al. 2009; Schøyen et al. 2019). Consequently, IMO adopted the International Convention on the Control of Harmful Anti-fouling Systems on Ships, banning its use on vessels since 2008. However, this regulation does not extend to obsolete ships, which are often the ones selected for sinking. While some countries have comprehensive guidelines and strict environmental regulations (for example,

see tinyurl.com/4szvtrdt), in others the high costs associated with the proper removal of such materials, together with the absence or poor enforcement of environmental regulations, make it more likely that some of these pollutants are released into the sea. For example, a significant oil plume emerged from the deployment site following the deployment of the Hu Shun Yu 809 (Figure 1c) in an important coastal tourist area of Patagonia. The growing number of obsolete ships raises concerns, as their deliberate sinking seems to be the only option, particularly in regions lacking strict protocols to mitigate environmental pollution (Miranda et al. 2020).

Not substitutes for natural reefs

Although artificial wrecks rapidly aggregate diverse benthic communities, these do not resemble those inhabiting natural reefs (Glasby and Connell 2001; Burt et al. 2009; Carvalho et al. 2013; Grasselli and Airoidi 2021). Even when wrecks and natural reefs may share many species, the ecological structure and function of these communities are rarely similar (Hill et al. 2021) (Figure 3). Differences

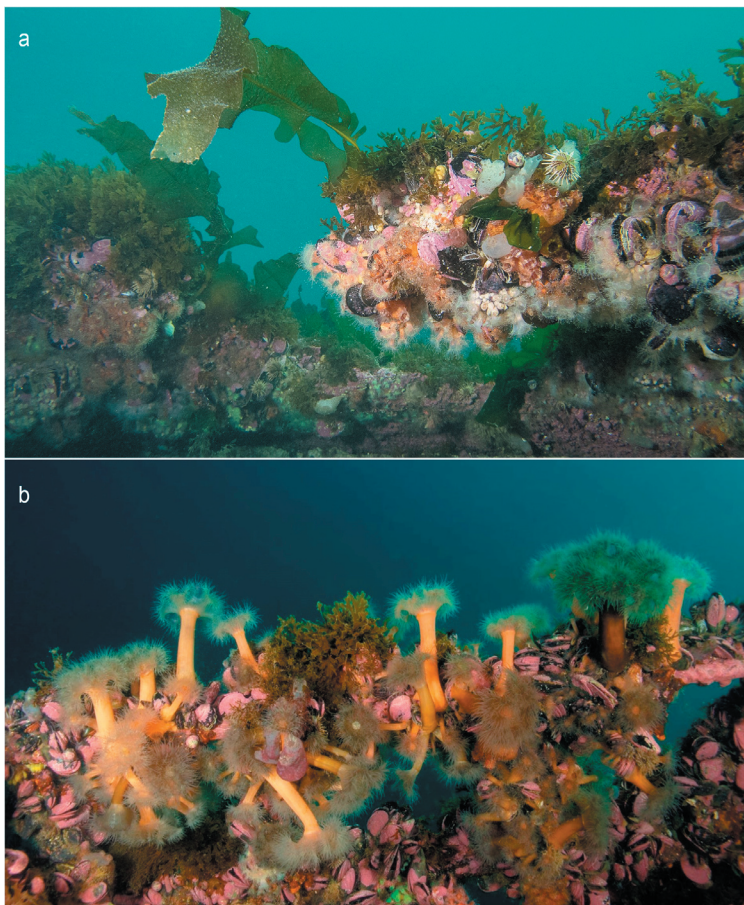


Figure 3. a) Rocky reef community in Patagonia and b) community at an artificial wreck site with similar depth. Even though many species may be shared between artificial wrecks and natural reefs, the structure and function of these communities are seldom alike. Photo credits: Nicolás Battini (a) and Gonzalo Bravo (b).

Figura 3. a) Comunidad de un arrecife natural rocoso en Patagonia Argentina y b) comunidad de un barco hundido a profundidades similares. Incluso cuando ambos hábitats comparten muchas especies, la estructura y función de estas comunidades no suelen parecerse. Créditos de las fotografías: Nicolás Battini (a) and Gonzalo Bravo (b).

in orientation, structural complexity, current exposure, material and age are mirrored in differences in the composition and abundance of the communities that grow on one and the other (Perkol-Finkel et al. 2006; Genzano et al. 2011; Fowler and Booth 2012; Sedano et al. 2020; Pinto et al. 2021). For example, Carvalho et al. (2017) found that the biomass of suspension feeders was higher in natural reefs while carnivores were more abundant in artificial ones, leading to differences in the trophic dynamics between habitats. Similarly, Lowry et al. (2017) found that artificial reefs typically attract a wider range of transient predators, resulting in higher consumption rates of prey species, even when fish density, biomass and richness were similar to natural reefs (Rilov and Benayahu 2000; Paxton et al. 2020). These structural differences between natural reefs and wreck communities can change organism behavior and species interactions (Ferrario et al. 2016). These changes, in turn, can modify more complex processes such as recruitment, succession or energy flow (Carvalho et al. 2013; Simon et al. 2013; Lowry et al. 2017). Far from being spatially restricted to the wreck itself, ecological alterations can propagate to natural environments (Fowler and Booth 2012). The provision of food or refuge not only creates novel feeding or spawning areas (Leitão et al. 2007), but also attracts organisms from nearby areas (Simon et al. 2011), decreasing their abundance on natural reefs and generating potential cascading effects when these organisms have an important ecological function in natural areas. Indeed, authors have suggested that the deployment of artificial wrecks may attract fish, making them more vulnerable to fishing mortality (Lowry et al. 2017) or act as ecological traps, a term that refers to the selection of poor-quality habitats with a decrease in fitness (Komyakova et al. 2021).

Favor the spread of invasive species

Artificial wrecks enhance the opportunities for marine non-native species to thrive in coastal environments. Invasive species can trigger irreversible alterations to biodiversity and ecosystems, such as causing local extinctions (IPBES 2023). These species are intrinsically associated with artificial structures and thrive in urbanized coastal areas such as ports, marinas and cities (Glasby et al. 2007; Schwindt et al. 2014; Ferrario et al. 2017; Giachetti et al. 2019). Hotspot areas for invasive species along the Southwestern Atlantic coast have been identified in the ports of Mar del

Plata, San Antonio Este and Oeste and Puerto Madryn (Reyna et al. 2023). Invasive species usually expand their distribution and colonize natural environments (Simkanin et al. 2012; Airolidi et al. 2015; Dafforn et al. 2012; Reyna et al. 2023; Carlton and Schwindt 2024).

Artificial wrecks offer a new settlement substrate for non-native species, acting as steppingstones and facilitating their dispersal into natural or even protected areas (Shelehy and Vik 2010; Simkanin et al. 2012; Miranda et al. 2020; Soares et al. 2020). For example, the sun coral *Tubastraea tagunensis* was documented in Brazilian coral reefs (Soares et al. 2020), causing a change in the biomass of fish (Mizrahi et al. 2017) and a reduction of the cover and recruitment of native reef-building corals (Miranda et al. 2016, 2018). In addition, the presence of the invasive oyster *Magallana gigas* was reported on the squid jigger vessel Hu Shun Yu 809 shortly after its deployment in northern Argentine Patagonia (Figure 1a) (Schwindt et al. 2019). Interestingly, further monitoring of the vessel led to the detection of two invasive ascidians, *Styela clava* and *S. plicata* (Castro et al. 2021). These three marine invasive species caused significant ecological and economic effects in other regions (da Rocha et al. 2009; Herbert et al. 2016) and were not previously recorded in the area. Invasive species, in particular, have shown high tolerance to antifouling biocides found in hulls and other artificial structures (Dafforn et al. 2012; McKenzie et al. 2012). For example, the hydroid *Ectopleura crocea*, rapidly colonizes wrecks surfaces, achieving the highest percentage coverage (Genzano et al. 2018). This differential recruitment may enhance invasion success at multiple stages, including facilitating transport and establishment (McKenzie et al. 2012).

Social concerns

The reinforcement of the paradigm that artificial wrecks promote marine conservation, coupled with traditional development approaches prioritizing short-term economic gains, may lead governments to relax regulations or implement policies that encourage their proliferation (Cullen-Knox et al. 2017). Such decisions could change the sustainable provision of some ecosystem services and, consequently, undermine long-term human well-being and lead to social conflicts due to inequitable access to specific ecosystem services by different individuals or groups

(Walker et al. 2004; Bennett et al. 2015; Sala and Torchio 2019). The current benefits from the deliberate sinking of ships are unbalanced in favor of certain stakeholders, which is a cause for concern. For instance, in Chubut province (Argentina), public access to the artificial wrecks is restricted by the provincial law, which provides exclusive right of use to authorized diving operators. This policy not only restricts access to local recreational divers, but also excludes non-profit diving clubs, generating tensions among stakeholders due to, in our opinion, an unfair distribution of costs and benefits.

In general, there is a lack of empirical understanding of the diversity of stakeholders, their motivations and preferences for valuing ecosystem services (Reed et al. 2009). A survey of divers found that artificial wrecks are not consistently perceived as an effective strategy for reducing pressure on sensitive habitats (Firth et al. 2023). In addition, some evidence suggests that divers appreciate shipwrecks as valuable diving sites for their historic component, which is lacking in artificial wrecks (Edney and Spennemann 2015). Consequently, the effectiveness of artificial wrecks in promoting tourism remains unclear, particularly given that divers often prefer historical sites and natural reefs (Şensurat-Genç et al. 2022; Firth et al. 2023). In Puerto Madryn, the relative contribution of diving activities to the overall tourism industry has remained relatively stable during the last decade despite the fact that ships have been deliberately sunk (Observatorio Turístico 2024). Furthermore, despite this, Puerto Madryn appears to be competing with Las Grutas (Argentina) to establish the “largest underwater park of South America”. This competitive dynamic underscores how the intentional sinking of ships can motivate neighboring regions to pursue similar initiatives.

MANAGEMENT IMPLICATIONS

Ship recycling facilities

The deployment of artificial wrecks constitutes one of the few available options for the final disposal of obsolete ships (Devault et al. 2017). Several factors including the scarcity and uneven distribution of ship recycling facilities, lead to most state-owned, abandoned or seized vessels being deliberately sunk, whenever they are not left to rust next to ports (Figure 1). Importantly,

alternative management strategies such as concentrating scrapping in a few countries may not necessarily be better from a social or environmental viewpoint (Devault et al. 2017). It is then imperative that environmentally and socially secure management strategies are promoted with the strengthening of legal and institutional settings to allow for the proper management of obsolete vessels. In many countries, there is a lack of standardized national regulations governing the preparation and deployment of artificial wrecks. For example, in Argentina, ships have been prepared for sinking in accordance with the regulations of each locality, often developed on an ad hoc basis. Although the national maritime authority has granted approval for sinking each of the cases mentioned in the text, there are significant dissimilarity in the infrastructure, stakeholders involved in scrapping and financial support. Also, in Brazil, there are plans to establish artificial wrecks near hard bottom ecosystems and marine protected areas along the coastline without standardized protocols (Miranda et al. 2020; Soares et al. 2020). Therefore, national or regional policies for the Southern Atlantic region are necessary. Regional initiatives in Europe started in 2009 with the International Convention for the Safe and Environmentally Sound Recycling of Ships and the European guidance for safer and greener ship recycling practices (bit.ly/47WpG6u). These kinds of initiatives are crucial to grant environmentally and socially secure alternatives to safely dispose of the increasing number of obsolete ships at a global scale.

Policies for artificial wrecks

The evidence pointing out that artificial wrecks do not form the basis for healthy marine ecosystems is increasing (Kelly et al. 2012; Heery et al. 2017; Komyakova et al. 2022). Unlike certain types of artificial reefs, they lack the design that pursues a specific conservationist objective. However, the demand for artificial wrecks continues. While the United Nations Conventions on the Law of the Sea provides a general framework for regulating activities in the marine environment, there is currently no international instrument that specifically addresses the regulation of any artificial reefs. For this reason, the guidelines on artificial reef placement of the London Convention and Protocol/UNEP have among their objectives to promote an approach that enables the construction of artificial reefs

in such a way that, even if a reef is primarily built for commercial purposes, such as fishing or tourism, it still provides environmental benefits. In addition, since the Convention on Biological Diversity, the conservation of biodiversity has been viewed through the lens of the adaptive ecosystem management (AEM) approach, which advocates for both environmental and social well-being (Waylen et al. 2014; Morgera 2016). A key aspect of the AEM of artificial wrecks is to better recognize and anticipate how wrecks will affect social and ecosystem processes, and that policies and decisions can be rapidly refined in the light of further knowledge (Kareiva and Fuller 2016). Achieving this requires the intimate coupling of scientific research with decision-making schemes (Sala and Torchio 2019), ensuring they incorporate adequate planning, monitoring and evaluation stages.

Engaging diverse stakeholders

All stakeholders, including local communities, should be integrated and participate in the decision-making process to achieve a fair distribution of benefits and potential risks across the different elements of the socioecosystem (Bennett et al. 2019; Noble et al. 2019). Limited studies have explored the diver perceptions of artificial wrecks as attraction sites (Stolk et al. 2005; Shani et al. 2012; Şensurat Genç et al. 2022). Yet, to our knowledge, there is still a lack of similar studies scrutinizing the public perception and social license for the intentional sinking of ships. While social media is replete with comments both supporting and opposing the practice, there has been no systematic assessment of the overall perception of all stakeholders. Surveys or interviews can help to assess public perceptions of the sinking of ships' benefits (Ramos et al. 2007), whether these vary by locality or individuals recognize that it interferes with other tourism activities they engage in or benefit from directly. Undertaking such participatory planning is challenging, as it requires important changes at the individual, collective and institutional settings (Sala and Torchio 2019).

A key complement of AEM strategies involves education and communication initiatives aimed at increasing the level of awareness related to ecosystem stability and integrity. As underwater eco-tourists, recreational divers enjoy healthy natural seascapes (Oh et al. 2008) and should advocate for the least impacting behaviors. Currently,

some courses for advanced recreational divers, such as specialization in ecology or species identification for marine conservation, are offered by diving certification companies. Expanding these educational programs to include concepts of eco-evolutionary processes that contribute to ecosystem stability and integrity is essential for aligning with the principles of ocean literacy and the Sustainable Development Goal (SDG) 14, proposed by the United Nations (Virto 2018). This type of ecosystem-based education would empower recreational divers in sharing their attitudes, preferences and decisions regarding the use and management of aquatic environments (Ha et al. 2020). It is anticipated that this approach will encourage recreational divers to enhance their appreciation, enjoyment and care of natural environments, fostering a deeper sense of ocean literacy.

CONCLUDING REMARKS

Artificial wrecks are currently valued tools for enhancing biodiversity and promoting the development of healthy aquatic communities. Here, we aim to challenge this paradigm by identifying and discussing undesirable consequences associated with artificial wrecks. Importantly, while we do not intend to advocate against further deployment of artificial wrecks, we strongly believe that they can produce unintended socioeconomic outcomes. Hence, we urge decision makers to undertake more integrative assessments of the potential impacts prior to their deployment, particularly where guidance and regulations are either lacking or not standardized. We also recommend a shift towards more participatory processes that recognize all stakeholders and involve local communities. This approach is crucial to support social acceptance of environmental risks and ensure transparency in the decision-making process (Cullen-Knox et al. 2017). Finally, we advocate for greener and safer options for ship recycling, given that artificial wrecks are typically a means of disposing of obsolete ships. The development of accessible, environmentally and socially safe ship recycling facilities, where vessels can be safely scrapped at the end of their lifespan, is then imperative to provide better alternatives to the deliberate sinking of ships.

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