Rev Fish Biol Fisheries (2023) 33:1199–1222
https://doi.org/10.1007/s11160-023-09790-7

REVIEWS

A global review of marine recreational spearfishing

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Received: 16 February 2023 / Accepted: 13 June 2023 / Published online: 21 August 2023

Abstract Recreational spearfishing is a fishing method that occurs globally, yet receives considerably less attention in the scientific literature relative to other recreational fishing methods, such as angling. Lack of scientific information on spearfishing may negatively affect the development and management of marine recreational fisheries. We conducted a systematic review of 102 peer-reviewed papers published between 1967 and 2022 pertaining to marine recreational spearfishing. Based on this literature review, we provide an overview of key insights across social, economic, and ecological dimensions of marine recreational spearfishing. While spearfishers represent less than 5% of marine recreational fishers, the participants are younger and may differ from recreational anglers in their motivations, with suggestions of increased well-being generated from a close connection with the sea during underwater fishing. Recreational spearfishers mostly target species of moderate to high levels of vulnerability that are mid to high trophic level carnivores. Though spearfishers

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11160-023-09790-7.

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can deliberately target larger individuals of exploited populations, this is not a generalizable pattern. Despite a growing body of research on the ecological impacts of marine recreational spearfishing, there is limited knowledge of these effects and their mechanisms across biological levels of organization (e.g., individual, population, community and ecosystem) compared with those of other fishing methods. Recreational spearfishers can contribute to advances in marine ecological knowledge, and inclusive participatory management could represent a key step towards transformative sustainable development of marine recreational spearfishing. Throughout the review, we identify gaps in the research and areas where future research is needed to better inform the socio-economic importance, ecosystem impacts and future management of marine recreational spearfishing.

Keywords Recreational fishing · Social dimension · Economic expenditure · Ecological impacts · Local ecological knowledge

Definition of marine recreational spearfishing

Spearfishing is the use of hand-held underwater gear to capture marine organisms such as fish, cephalopods and crustaceans. Underwater refers exclusively to fishing actions undertaken by means of freediving, SCUBA diving or hookah diving (Fig. 1). The most common underwater harvesting gear are spearguns, pole spears, and Hawaiian slings. However, more rudimentary tools can also be used, such as hand spears or hand hooks (Fig. 1). Recreational spearfishing is defined as "fishing of aquatic organisms that neither constitute the individual's primary source of nutrition nor are sold or otherwise traded on any market" (FAO 2012). Thus, while a key motivation of recreational spearfishers may relate to catching food, unlike commercial or subsistence fishers, these activities are not integral to the livelihood or nutritional needs of the individual and their family (FAO 2012).

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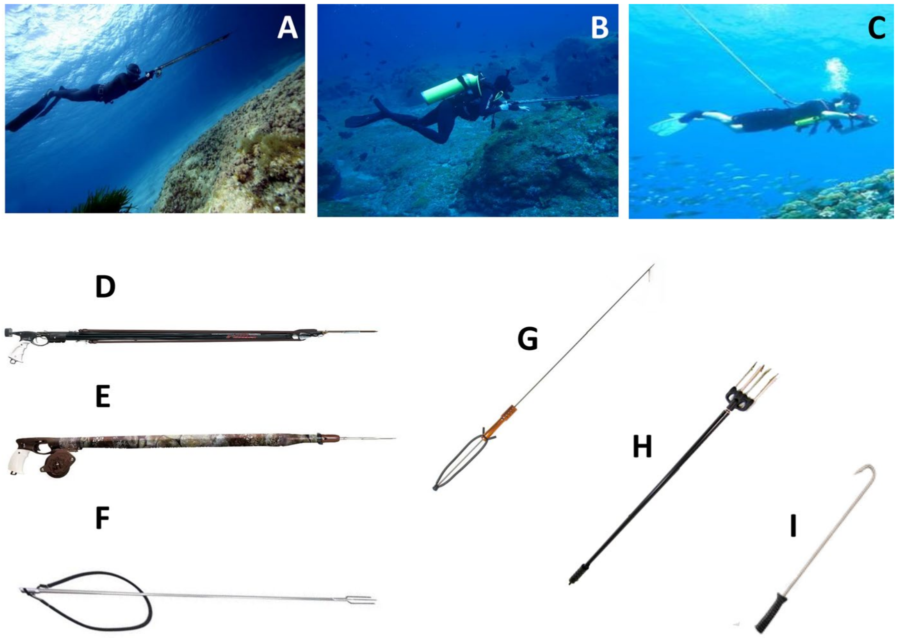

Fig. 1 Spearfishing can be practiced by means of three main diving techniques: freediving (**A**); scuba diving (**B**); and hookah diving (**C**). Spearfishers can use a variety of underwater gear such as spearguns with slings (**D**) or pneumatic (**E**), pole spears (**F**), Hawaiian slings (**G**), hand spears (**H**), or hand hooks (**I**). Source of pics: (**A**, **D**, **E**, **I**: Marco Bardi; B: Sisbiota-Mar; **C**, **F**, **G**, **H**: from the manufacturers' websites)

Introduction

The act of catching aquatic organisms with a spear is an ancient human activity that dates back at least 90,000 years (Yellen et al. 1995), likely preceding the development of more complex gear types, such as hooks, nets, and lines. Presently, spearfishing is practiced for recreational, subsistence, or commercial purposes. While scientific literature pertaining to recreational fishing has primarily focused on rod-and-line angling (e.g., Cooke et al. 2019, 2021; Lewin et al. 2019), there may be social, economic, and ecological differences between recreational angling and spearfishing (Gordoa et al. 2019; Sbragaglia et al. 2020b), such that it is crucial to devise specific management actions for each sector.

Spearfishing may differ from other recreational fishing methods in several ways. First, spearfishers often diverge demographically and attitudinally from anglers. For example, spearfishers have been found to report greater satisfaction related to their catch and associated activity when compared to anglers (e.g., web-surveyed Spanish recreational fishers; Gordoa et al. 2019; see also "Discussion of social and economic aspects" section) and appear to show different engagement dynamics on social media relative to recreational anglers (Sbragaglia et al. 2020b; see also "Discussion of social and economic aspects" section). Second, in contrast to most types of recreational fishing, spearfishing is an active, underwater method of fishing where, almost uniquely, fishers are able to select which individuals they harvest because they can visually identify and selectively target all potential catch (Pavlowich and Kapuscinski 2017). Third, spearfishers use several "hunting" techniques that are more behaviorally comparable to those used by natural predators (e.g., ambush, sit-and-wait, or active hunting strategies) than other fishing methods such as angling or netting. Thus, spearfishing may trigger defensive behaviors in targeted species that are analogous to natural anti-predator responses (Samia et al. 2019). Fourth, the selectivity patterns of spearfishing may differ from other fishing methods because of the depth limitations of spearfishers, especially in freediving (Lindfield et al. 2014; Sbragaglia et al. 2020b). Combined, these attributes of recreational spearfishing could drive differences in socio-economic and ecological outcomes of spearfishing relative to other fishing methods. For example, recreational spearfishing could foster unique psychological and social drivers, such as a stronger connection with the marine environment and different motivation for fishing compared to angling. Recreational spearfishers could also provide a unique form of local ecological knowledge, including a distinct sensitivity in understanding and monitoring changes of marine ecosystems due to their perspective of the underwater environment. Furthermore, the selective and active nature of spearfishing could potentially drive distinct cascading effects on ecosystem processes and functioning different to that expected from other fishing methods (e.g., cascading effects from selective predator removal; Scheffer et al. 2005). However, differences in socio-economic and ecological outcomes of spearfishing relative to other recreational fishing methods are largely hypothetical and, when scientific evidence is available, it is not synthetized and accessible for managers and policy makers. The consequences of this lack of knowledge could result in poor management decisions about spearfishing with respect to other fishing methods. On one hand, excessive limitations of the activity of spearfishers could negatively affect socio-economic outcomes. On the other hand, lack of appropriate and tailored management regulations for spearfishers could have negative ecological consequences. Therefore, it is critical to provide an updated synthesis of socio-economic and ecological aspects of spearfishing to inform managers and policy makers and guide future research activity. This is largely available for recreational fisheries as a whole (e.g., Cooke et al. 2019, 2021; Lewin et al. 2019), but much of this is related to rod-and-line angling, and consequently not useful for addressing specific challenges in management and research of recreational spearfishing.

We first conducted a systematic review of published peer-reviewed research papers including both marine recreational and subsistence/artisanal/commercial spearfishing. This was done to compare between recreational and other forms of spearfishing in terms of geographical and temporal patterns. We then developed an integrative review to characterize and synthesize the main topics of research on social, economic, and ecological dimensions of marine recreational spearfishing. Specifically, we focused on demography and motivation for the social dimension, expenditure for the economic dimension, while for the ecological dimension we synthetize information on catch per unit effort, selectivity, change in behavioral phenotypes, and local ecological knowledge. Though our review focuses on marine recreational spearfishing, many aspects may be applicable to freshwater recreational spearfishing as well as to subsistence, artisanal, or commercial spearfishing. We mainly address spearfishing of finfishes where it is necessary to use spearguns, pole spears, or Hawaiian slings to catch the target species. However, we recognize that cephalopods (e.g., cuttlefish and octopuses), crustaceans (e.g., crabs and lobsters), molluscs (e.g., scallops and bivalves), and echinoderms (e.g., sea urchins and sea cucumbers) may also be harvested by spearfishers with rudimentary gear such as hand spears, hand hooks, or taken by bare hands in distinct regions of the world.

Methodological approach

We used the keywords "*spearfishing*" or "*spear fishing*" to search published peer-reviewed papers (written in English) on Web of Science and Scopus databases. We identified and retrieved a total of 462 papers based on queries of the two databases on 21st of April 2022 (see diagram referring to the Preferred Reporting Items for Systematic Reviews and Meta Analyses, PRISMA, in Figure S1). After a first screening of titles and abstracts, we excluded 268 papers mainly because they were not related to spearfishing. The large proportion (49%) of these papers referred to the genus *Tetrapturus*, which comprises several fish species commonly known as "spearfish" (e.g., Mediterranean spearfish, *Tetrapturus belone*). Next, we accessed the full-text version of the remaining papers and excluded 47 of them because they were related to freshwater spearfishing, to fishing with a spear from outside of the water or to papers where spearfishing was not empirically evaluated, but only referred to anecdotally as a possible cause of the observed ecological patterns. After these two screenings, we retained 147 papers related to marine spearfishing for further analyses (Fig. S1; Table S1).

With the 147 published papers, we conducted a systematic review of the full-text documents to determine their spatial, temporal, and thematic scope. We extracted the following information ("Results of the systematic review" section): (1) geographic location where the study was conducted; (2) year of publication; (3) whether the study was related to recreational or other forms of spearfishing (i.e., subsistence, artisanal, or commercial); (4) whether the study evaluated spearfishing as a response or predictor (i.e., research on spearfishing), versus whether spearfishing was used as a sampling method or metric for other purposes or inquiry (e.g., for tracking changes in marine ecosystems); and (5) the main research dimension of the study, which included the following: ecological (e.g., catch composition or fish behavioral response to spearfishing), social (e.g., human motivations and fishing activity satisfaction), or economic (e.g., expenditures).

Focusing on the subset of published papers exclusively related to marine recreational spearfishing, we built a co-occurrence network with the keywords that most often appear in the abstract of the studies to have a comprehensive view of the topics of interest of the studies and how such topics were connected among them. We cleaned the text of the abstracts of the papers by removing numbers, stopwords and punctuations. Subsequently, we tokenized the text by isolating all the possible two-words combinations and quantified their frequency of occurrence. Then, we created a co-occurrence matrix to visualize the connections between the different words that occurred at least five times. This allows one to identify the pattern of connections between co-occurring words suggesting their importance in the entire body of literature and also provide insight about the strength and centrality of specific words (e.g., Lozano et al. 2019). The visual display of the network was organized according to the Fruchterman-Reingold layout, which is a force-directed layout algorithm which treats edges (i.e. words) like springs that move vertexes closer or further from each other in an attempt to find an equilibrium that minimizes the energy of the network (Csardi and Nepusz 2006). Furthermore, we analyzed the structure of communities in the network using a fast greedy modularity optimization algorithm (Clauset et al. 2004), which highlights how co-occurring networks of words may cluster around specific topics indicating main research interest. We ran quantitative analysis of comments in R version 3.5.0 (R, Core Team 2018) with the additional packages "*quanteda*" (Benoit et al. 2018), and "*igraph*" (Csardi 2013).

Results of the systematic review

The papers analyzed during the systematic review were published from 1967 to 2022. Of the 147 selected papers, 102 (69%) focused on recreational spearfishing and 45 (31%) on subsistence, artisanal, or commercial spearfishing. The latter 45 were grouped as "others" because the main focus of this review was marine recreational spearfishing. Of the 102 marine recreational spearfishing papers (Table S1), 65 (64%) directly investigated spearfishing and 37 (39%) used spearfishing for other purposes. Of the remaining 45 papers focusing on other forms of marine spearfishing (i.e., subsistence, artisanal, or commercial), 34 (76%) directly investigated spearfishing and 11 (24%) used spearfishing for other purposes. In the following sections we describe the geographical distribution, the temporal pattern, and the research dimensions of the 147 papers included in the systematic review. However, considering that the focus of the review is recreational spearfishing, we only synthesized the social, economic, and ecological dimensions of the 102 marine recreational spearfishing papers ("Discussion of social and economic aspects" and "Discussion of ecological aspects" sections; Table S1).

Geographical distribution

Published papers related to marine recreational spearfishing activities were distributed across the globe, and were particularly concentrated in the northeastern Atlantic Ocean and the Mediterranean Sea (74% in developed countries; Fig. 2A). By contrast, scientific papers related to other forms of spearfishing were also distributed across the globe, but were more heavily concentrated in the western and central Indo-Pacific and the Caribbean Sea (11% in developed countries; Fig. 2A). This could highlight the dominant type of spearfishing that occurs in those areas or may also represent a publishing or research bias. For example, we did not identify any paper dealing with commercial spearfishing from Europe, which is a minor activity compared to the magnitude of recreational spearfishing, but countries such as Italy allow a limited number of commercial spearfishing licenses (V.S. personal observation). Studies related to research on spearfishing were distributed widely around the world (56% in developed countries), while papers using spearfishing for other scientific purposes (e.g., tracking distributional range shifts using local ecological knowledge) were mostly confined to the Mediterranean and the Caribbean seas (51% in developed countries; Fig. 2B).

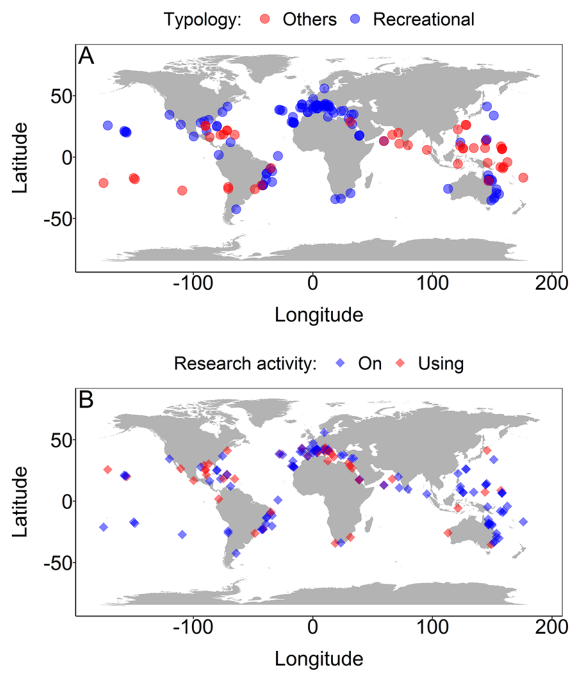

Fig. 2 Geographical distribution of the published papers identified during the systematic review according to; **A** the typology of spearfishing (i.e. recreational or others, i.e., subsistence, artisanal or commercial) and **B** whether the papers were related to research on spearfishing or using spearfishing for other scientific purposes

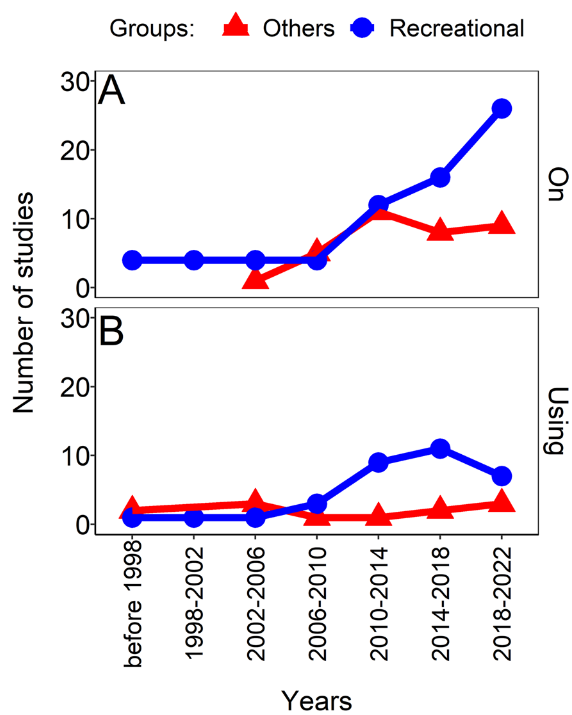

Fig. 3 The total number of new studies published per 4-year time period related to spearfishing, as identified during the systematic review. The papers were grouped according to the spearfishing typology (recreational or others, i.e. subsistence, artisanal or commercial) and whether the papers were related to **A** research on spearfishing or **B** using spearfishing for other purposes

Temporal pattern

In the last decade, there has been an increase in the number of published papers on marine recreational spearfishing relative to those on other forms of spearfishing (Fig. 3A). For example, in 2006–2010 only four studies were published characterizing marine recreational spearfishing, while in 2018–2022, 26 papers were published on this topic (Fig. 3A). In 2006–2014, there was also an increase in the number of studies published on other forms (i.e., subsistence, artisanal, or commercial) of spearfishing, with 10 papers published on this topic in 2010–2014, though the number of new papers published on this topic has declined slightly since 2014 (Fig. 3B), suggesting an increasing interest in empirical study of marine recreational spearfishing relative to other forms of spearfishing. In 2010–2018, we also observed an increase in the number of studies using recreational spearfishing for other research purposes, but this has declined slightly since 2018–2022 (Fig. 3B). By contrast, the number of studies investigating other forms of spearfishing for other purposes has remained consistently low over time (Fig. 3A, B). As an important caveat, results for 2022 represent only 4 months (i.e., papers we accessed in April 2022), which could affect our observed temporal trends.

Research topics and dimensions

Of the 102 published studies on marine recreational spearfishing, the ecological dimension was most commonly studied (90 studies) relative to social (20) and economic (6) dimensions (Table S1). The majority of studies investigated topics related to only one of the three research dimensions, i.e. ecological, economic, or social (93 out of 102 studies; Table 1). By contrast, only a few papers investigated all the three dimensions simultaneously (4 out of 102; Table 1).

Table 1 List of papers (n = 53) that directly investigated ecological aspects of spearfishing in different areas during recreational fishing trips (Tourn = no) and tournaments (Tourn = yes)

Paper	Area	Tourn	CPUE Kg/h [fish/h]	IVI	Trophic level	Behavior	Size selection
Barbosa et al. (2021)	Brazil	No	0.98		3.44		X
Benevides et al. (2016)	Brazil	No				X	
Benevides et al. (2018)	Brazil	No				X	
Bradford et al. (2019)	Australia	No					
Cinelli and Fresi (1980)	Italy	Yes	0.62				
Coll et al. (2004)	Spain	Yes	1.10				X
Curley et al. (2013)	Australia	No					X
Dedeu et al. (2019)	Spain	No					
Diogo and Pereira (2013)	Azores	No	1.08	47.60			
Diogo and Pereira (2014)	Azores	No	1.97 [2.30]				
Diogo et al. (2017)	Portugal	No	1.37 [2.69]	50.60	3.45		
Diogo et al. (2020)	Portugal	No					
Espedido et al. (2014)	Philippines	Yes	2.00[a]				
Foo et al. (2021)	Hawaii	No					
Frisch et al. (2008)	Australia	No	2.22 [1.08]				X
Frisch et al. (2012)	Australia	No					
Giglio et al. (2018)	Brazil	No					
Giglio et al. (2020)	Brazil	No					
Guabiroba et al. (2020)	Brazil	No	2.60				
Hall et al. (2021)	Australia	No					
Harmelin-Vivien et al. (2015)	France	No					
Harper et al. (2000)	USA	No	[1.50][a]				X
Herfaut et al. (2013)	France	No					
Jiménez-Alvarado et al. (2020)	Spain	No	0.65	55.50			X
Johnson et al. (2019)	USA	No					
Jouvenel and Pollard (2001)	France	No					X
Lincoln Smith et al. (1989)	Australia	Yes	1.45				X
Lloret and Font (2013)	Spain	No		54.15			
Lloret et al. (2008)	Spain	No	1.36	54.15	3.89		X
Lowry and Suthers (2004)	Australia	No		46.00	2.80		X
Mann et al. (1997)	South Africa	Yes	1.18				X
Martínez-Escauriaza et al. (2020)	Madeira	No	0.92[a] [1.30][a]				
Martín-Sosa (2019)	Spain	Yes	0.39	45.72	3.24		X
Maya-Jariego et al. (2022)	Spain	No					
Meyer (2007)	USA	No	1.13				X
Michailidis et al. (2020)	Cyprus	No	0.50[b]		3.70		
Morales-Nin et al. (2005)	Spain	Yes	0.59[a]				X
Nunes et al. (2012)	Brazil	No	[1.70][a]				
Nunes et al. (2016)	Brazil	No				X	
Nunes et al. (2019)	Brazil	No				X	
Papadopoulos et al. (2022)	Greece	No	0.20[c]				
Pita and Freire (2016)	Spain	Yes	1.60	36.70			
Rocklin et al. (2011)	France	No					
Roos and Longo (2021)	Brazil	No					X
Sangil et al. (2013)	Spain	No					

Table 1 (continued)

Paper	Area	Tourn	CPUE Kg/h [fish/h]	IVI	Trophic level	Behavior	Size selection
Sbragaglia et al. (2018)	France, Spain	No				X	X
Sbragaglia et al. (2020b)	Italy	No					X
Sbragaglia et al. (2022)	Italy	No					
Skov et al. (2020)	Denmark	No					
Sluka and Sullivan (1998)	USA	No					X
Stamoulis et al. (2019)	USA	No				X	X
Zarauz et al. (2015)	Spain	No	0.08[a]				
Zeller et al. (2003)	Australia	No					

Values of CPUE were standardized to kg/spearfisher/hour or number of fish/spearfisher/hour, the latter between square brackets

[a]From kg or fish/day to kg or fish/hour under the assumption that an average spearfishing trip is approximately 4 h

[b]From kg or fish/year to kg or fish/hour under the assumption of an average number of fishing trips of 30 fishing days per year). Intrinsic Vulnerability Index is reported (IVI) together with trophic level of targeted species, and whether the article investigated fish behavioral response (behavior) or aspects of size selectivity of spearfishing

The co-occurrence analysis showed two main word networks composed by three different communities (Fig. 4; Table S2). The first network was composed by one main community centered around the words "*recreational*" and "*fishing*", which was linked to two other communities: one centered around the word *"management"*, and the other centered around the words *"marine"* and *"reserve"* (Fig. 4; Table S2). The second network was composed by one main community centered around the word *"fish"*, which was linked to two other communities: one centered around the words *"total"* and *"catch"*, and the other centered around the word *"reef"* (Fig. 4; Table S2). Other small communities with terms such as "*goliath grouper*", "*body size*", "*visual census*", "*trophic level*", and "*social media*" were also identified (Fig. 4; Table S2).

Discussion of social and economic aspects

Social aspects

We identified 19 published papers that directly investigated the social aspects of marine recreational spearfishing. According to the reviewed studies, spearfishers make up less than 5% of marine recreational fishers in countries such as Spain (Morales-Nin et al. 2005; Pita et al. 2018; Gordoa et al. 2019), Denmark (Skov et al. 2020), and South Africa (Mann et al. 1997). The average age of recreational spearfishers varied among countries, and was 30 years (South Africa; Mann et al. 1997), 33 years (Portugal; Assis et al. 2018; Martínez-Escauriaza et al. 2020), and 36–37 years (Spain and Jamaica; Ennis and Aiken 2014; Pita et al. 2018; Gordoa et al. 2019). Web-surveyed Spanish recreational spearfishers were younger (36 years) than recreational shore (41) and boat (45) anglers (Gordoa et al. 2019). This result is also supported by a recent on-site survey about recreational fishing, conducted in Catalonia (Spain), which reinforced the finding that recreational spearfishers are younger (37) than recreational shore (48) and boat (53) anglers (Vitale et al. 2021). Given the physical nature of spearfishing (especially in freediving), the pattern is not surprising and may extend to other countries and regions. We presume that the physical fitness required to practice recreational spearfishing, especially freediving, is more demanding than that required by other forms such as recreational angling.

Outdoor activities, such as recreational fishing in general, provide a range of social, psychological, and physiological benefits (Manfredo et al. 1996; Parkkila et al. 2010; Fig. 5). Though there is less published information on the motivations and received benefits of recreational spearfishers compared to recreational anglers, spearfishing has both catch and non-catch motivations, similar to the case of angling (Fedler and Ditton 1994). The acquisition of high quality food can also be an important motivation for many recreational fishers, particularly those that use lethal methods, such as spearfishers (Assis et al. 2018; Terlizzi et al. 2022), and where the decision to target and harvest the fish is a deliberate choice (Cooke et al. 2018).

Fig. 4 Co-occurrence network analysis of the most common keywords used in the abstract of the 102 published studies analyzed here. The width of the edges (i.e., grey lines) between nodes (i.e., words) represents the strength (i.e., the sum of weights attached to ties belonging to a node; see also Table S2). The network is organized according to the Fruchterman-Reingold layout, while colored areas represent community structure resulted by a fast greedy modularity optimization algorithm (see methods for more details)

For example, among the many identified non-catch related motivations for recreational spearfishers in Portugal, one of the main motivations was "to be in touch with the sea" (Assis et al. 2018). Moreover, recreational spearfishing provides different social benefits relative to angling, as shown by web-surveyed Spanish recreational spearfishers that report higher levels of catch and activity satisfaction than recreational anglers (Gordoa et al. 2019).

The additional social benefits related to spearfishing may relate to the underwater experience (Young et al. 2016), but robust scientific evidence is still lacking (Januchowski-Hartley et al. 2020). In Italy, recreational spearfishing videos triggered strong appreciation for the freediving and fishing actions displayed on social media, something not observed for anglers (Sbragaglia et al. 2020b). Indeed, spearfishers use the term "aquaticity" to refer to their capacity to relax and move in a fluid and smooth way underwater. A compelling and systematic review on the term "aquaticity" highlighted how human contact with the water could promote physical as well as psychological and emotional well-being (Varveri et al. 2016). Images and sounds of marine ecosystems have also demonstrated beneficial psychological and physiological effects that include reducing stress, and helping reduce sleep disorders and depression (Bratman et al. 2019). Moreover, the human body undergoes physiological changes when diving, especially freediving (i.e., the human diving response; Foster and Sheel 2005), some of which could result in evolutionary adaptations. For example, the indigenous *Bajau* people (in southeast Asia; Abrahamsson and Schagatay 2014) evolved an increased spleen size (an adaptation to providing them with a larger reservoir of oxygenated red blood cells during spearfishing diving) and other adaptations related to genes controlling the diving response (Ilardo et al. 2018). Although recreational spearfishing and angling provide health benefits associated with experiencing blue spaces (Pretty et al. 2006), it is plausible that social, psychological, and physiological benefits associated to the underwater aspects of recreational spearfishing differ from those of recreational angling, but no rigorous comparisons exist.

In summary, spearfishers represent a younger numerical minority within the population of marine recreational fishers, but other demographic information (e.g., gender, race, socioeconomic status) is currently limited. They have a strong motivation to be underwater, may generally be in good physical condition, and may experience higher well-being rewards from spearfishing activity relative to anglers. Future research is especially needed on the demographics of recreational spearfishers, to better inform the social implications of this activity and its cultural importance relative to recreational angling. Additional research should also evaluate whether the athletic performance required for practicing recreational spearfishing could promote a healthier lifestyle and state of well-being—as well as exposing spearfishers to risks such those related to hypoxia and blackout (e.g., Lindholm and Lundgren 2009)—relative to other recreational consumptive (e.g., recreational angling) and non-consumptive (e.g., scuba diving) recreational activities.

Economic impact

We identified six published papers that investigated certain economic aspects of recreational spearfishing. Several of these studies contained expenditures related to spearfishing, which often differ by region within and across countries. For example, in Spain, recreational spearfishers in Catalonia spent roughly €800 per person per year in acquiring goods and services directly related to spearfishing activities (Lloret et al. 2008), versus €1700 per year in Galicia (Pita et al. 2018). For comparison, in the Canary Islands, Jiménez-Alvarado et al. (2020) estimated that recreational spearfishers spent on average €484 as an initial investment in equipment, and then an average annual expenditure of €245 (including travel, maintenance, equipment replacement, insurance and a fishing license). The estimates for Catalonia and Canary Islands are similar to the estimates for Spanish marine recreational fishers (€672 per year; Hyder et al. 2018), while estimates for Galicia are twice as much. This may be related to the fact that GDP is higher in the Atlantic than in the Mediterranean areas with obvious repercussion on recreational fishing expenditure (Hyder et al. 2018). Economic estimates for mainland Portugal also report that 65% of recreational spearfishers spent less than €500 per year in direct expenditures related to the activity (namely on equipment and trips), while the remaining 35% spent over €500 per year for the same expenditures (Assis et al. 2018). This estimate is lower than that obtained by Hyder et al. (2018) for the average annual spending by Portuguese marine recreational fishers considering all fishing methods (€796; Hyder et al. 2018). This may be expected since the great majority of marine recreational fishers in Portugal are shore anglers with lower income and with less expenditures than spearfishers and boat anglers (Diogo et al. 2020). In Cyprus, recreational spearfishers spent on average €748, which is less than what was estimated for marine recreational anglers in the same study (Michailidis et al. 2020), but it is more than double that of previous estimates of expenditure for marine recreational fishers in Cyprus (€300; Hyder et al. 2018).

Most recently, two studies characterized the economic impact of spearfishing tournaments in Australia and Italy respectively, both of which demonstrate the local economic value of spearfishing tournaments and suggest trading-off the economic dimension with social benefits and potential ecological impacts (Schilling et al. 2022; Terlizzi et al. 2022). Although two recent papers have estimated the economic importance of recreational fishing at global (Cisneros-Montemayor and Sumaila 2010) and regional levels (Hyder et al. 2018), specific estimates for spearfishing are missing. The comparison with economic expenditure of European marine recreational fishers (Hyder et al. 2018), suggests that spearfishers may spend more or less than recreational anglers with contrasting patterns across countries and regions. To understand the full spectrum of the economic contribution of recreational spearfishing, future research should move beyond the current characterization of expenditure and investigate the *knock-on* effects of the activity on other economic sectors (Dyck and Sumaila 2010), as well as the economic and socio-cultural values of ecosystem services provided by spearfishing activities relative to other activities (De Groot et al. 2012). This is especially important because many countries separately manage recreational spearfishing and recreational angling, such that economic evaluations specific to recreational spearfishing could be important to ensure balanced and fair management decisions.

Discussion of ecological aspects

Catch per unit effort and catch characteristics

Among the 53 reviewed papers that investigated ecological aspects of recreational spearfishing, 23 estimated catch per unit of effort (CPUE; see also Table 1). "*Fishing effort*" also appeared in the central network of the co-occurrence analysis (Fig. 4). All except 2 studies out of the 23 (which reported CPUE as number of fish per day, Table 1) reported biomass of fish extracted by spearfishers per year, day, or hour. Therefore, we were able to standardize harvest rate estimates using a general assumption based on the literature review (i.e., 30 fishing days per year; 4 h per day; considering only most recent values where trends in CPUE were reported) or information presented in the paper (Table 1). Values of CPUE indicated that estimated fishing efficiency varied from 0.08 to 2.6 kg/spearfisher/hour (Table 1). These values are similar to those found for artisanal spearfishing in the Indo-Pacific, which average between 0.5 and 2 kg/spearfisher/hour (Hamilton et al. 2012; Cohen and Alexander 2013; Januchowski-Hartley et al. 2014; Humphries et al. 2019) during normal fishing activities. However, these values fall significantly below the 3.6–9 kg/spearfisher/hour that has been estimated for night spearfishing, or when targeting spawning aggregations (Hamilton et al. 2012; Rhodes et al. 2018).

Comparison of CPUE estimates may not always be appropriate due to the different spatial and temporal scales and methods used. CPUE was estimated during different types of activities, including both recreational activity (15 out of 23) and tournaments (8 out of 23), different time periods (spanning 1996–2022), across several regions of the world, sites with different histories of exploitation, and with considerable differences in catch composition both relative to species targeted and number of species harvested. Tournament data are particularly useful for CPUE comparisons as they allow for longitudinal data analysis and comparisons across controlled conditions in space and time (e.g., sites with similar histories of exploitation, similar catches with regards to species targeted and harvested, under the same environmental conditions, and with the same gear requirements and fishing restrictions), while also representing individual heterogeneity among participants. For example, large differences in CPUE have been documented among participants within the same tournament (Lincoln Smith et al. 1989; Coll et al. 2004), as well as among different types of tournaments (Cinelli and Fresi 1980; Pita and Freire 2014). The drivers governing such differences are still unknown, but Terlizzi et al. (2022) showed that CPUE of spearfishers swimming out from the shore is half that of spearfishers using a boat during tournaments, potentially due to access to fish or to physical effort, which may be of relevance to assessment and management.

The average intrinsic vulnerability index of fishes (i.e., an index ranging from 0 to 100, which integrates life history and ecological characteristics of marine fishes to estimate their intrinsic vulnerability to fishing; Cheung et al. 2005) harvested within recreational spearfishing catches was reported in eight papers from the Mediterranean Sea, North-East Atlantic Ocean, and Australia (Fig. 4; see also Table 1). These values spanned from 36.7 (moderate) to 55.5 (high) intrinsic vulnerability. The trophic levels of species targeted by recreational spearfishers were reported in six papers and ranged between 3.24 and 3.89 (Table 2). This suggests that recreational spearfishers mostly target species of moderate to high levels of vulnerability that are mid- to high-trophic level carnivores.

Selectivity of recreational spearfishing and potential effects on marine ecosystems

Among the 53 reviewed papers that directly investigated ecological aspects of recreational spearfishing, 19 were directly or indirectly related to the size of the fish targeted by recreational spearfishers, and "*body size*" and "*highly selective*" appeared as relevant nodes in the co-occurrence analysis (Fig. 4). Of these 19 papers, only three provided evidence that recreational spearfishing targets larger individuals compared with other fishing methods (e.g., recreational angling) that target the same species (Dalzell and Smith 1998; Harper et al. 2000; Frisch et al. 2008). Recent evidence suggests that in some instances recreational angling may select for larger common dentex, *Dentex dentex* than recreational spearfishers (Marengo et al. 2015; Sbragaglia et al. 2020b), which could be an emerging pattern linked to technological innovations, such as underwater cameras, boat-based electronics and use of live prey as bait (Cooke et al. 2021). Therefore, management actions aiming to mitigate the impact of selective harvesting of larger individuals should carefully consider updated information for the target species in light of recent technological innovations.

We did not find papers that directly addressed the unique effects of recreational spearfishing (relative to other fishing methods) on biomass and food-web dynamics. Spearfishing has been shown to reduce the abundance of exploited predatory species (Godoy et al. 2010; Giglio et al. 2017; Hall et al. 2022). This in turn can reduce density-mediated and risk-mediated effects of these species on prey and competitor populations, with top-down cascading effects on prey and competitive release on community structure and potential changes in ecosystem functions (Baum and Worm 2009; Estes et al. 2011). A classic example—not related to spearfishing—is that overexploitation of otters (i.e., top predators) may lead to explosion of their preys (i.e., mesopredators or grazers) and consequently kelp forest overgrazing (Estes et al. 1978). However, whether similar cascading effects can or has occurred for marine recreational spearfishing in a mixed coastal fisheries context is unknown, and represents an important aspect to address in future research. Furthermore, an additional aspect to consider in this context is that both top predators (i.e., sharks) and humans could present similar lethal threat to mesopredatory fishes in coastal marine systems (Asunsolo-Rivera et al. 2023), with potentially similar implications in controlling top down cascading effects.

One study identified additional effects of recreational spearfishing on marine ecosystems related to inadvertently damaging important habitats such as corals in areas that experience high levels of fishing effort (Giglio et al. 2018). However, it is possible that such damage is less than that associated with other fishing methods, because there may be fewer anchor deployments per trip compared to angling (Frisch et al. 2008). Therefore, recreational spearfishing may exert lower levels of habitat and environmental damage compared with other fishing methods because there is essentially no discarded gear, little if any bycatch, no requirement for bait, and less littering (Frisch et al. 2008; Diogo et al. 2020).

Changes in behavioral phenotypes of fishes

We identified six papers that estimated the effects of spearfishing on fish behavior (Table 1). The most common behavioral traits measured in these studies reportedly influenced by spearfishing were related to anti-predator behavior (a focus on such behavior is supported by "*antipredator behavior*" appearing as relevant nodes in the co-occurrence analysis; Fig. 4). Antipredator behavior was quantified using a number of metrics, the most common of which was flight-initiation distance, which is defined as the distance at which a prey flees from an approaching predator (Ydenberg and Dill 1986; Stankowich and Blumstein 2005). There is strong agreement among studies that recreational spearfishing pressure increases flight-initiation distance of targeted species, which aligns with studies showing that passive fishing gear (e.g., hook-and-line, traps and stationary nets) can trigger a "timidity syndrome" in exploited

Table 2 List of papers (n = 37) that used spearfishing for other scientific purposes

Paper	Area	Tourn	Use	Context	Video photo	Social media
Adel et al. (2022)	Egypt	No	Hap	Non-indigeNous species	Yes	Yes
Aguilar-Perera and Carrillo-Barragán (2019)	Mexico	No	Hap	New species occurrence	Yes	No
Arechavala-Lopez et al. (2018)	Spain	No	Syst	Escaped farmed fish	No	No
Barcelos et al. (2018)	Portugal	No	Hap	New species occurrence	Yes	No
Bender et al. (2014)	Brazil	No	Syst	Exploitation	No	No
Boada et al. (2017)	Spain	Yes	Syst	Fish assemblage	No	No
Bulleri and Benedetti-Cecchi (2014)	Italy	No	Syst	Fish assemblage	Yes	No
CastellaNos-Galindo et al. (2018)	Colombia	No	Syst	Exploitation	No	No
Cavallaro et al. (2016)	Italy	No	Hap	Non-indigeNous species	No	No
Chapman and Kramer (1999)	Barbados	No	Syst	exploitation	No	No
Dahl and Patterson III (2014)	USA	No	Syst	Non-indigeNous species	No	No
Dahl et al. (2016)	USA	No	Syst	Non-indigeNous species	No	No
Esposito et al. (2021)	Italy	No	Hap	Non-indigeNous species	No	No
Fairclough et al. (2008)	Australia	No	Syst	Fish assemblage	No	No
Giddens et al. (2014)	USA	No	Syst	Non-indigeNous species	No	No
Gledhill et al. (2015)	Australia	Yes	Syst	Distribution shift	Yes	No
Hutchings and Griffiths (2010a)	South Africa	Yes	Syst	Exploitation	No	No
Hutchings and Griffiths (2010b)	South Africa	No	Syst	Fish biology	No	No
Irigoyen-Arredondo et al. (2022)	Mexico	No	Syst	Fish assemblage	No	No
Jimenez et al. (2022)	Cyprus	No	Hap	Fish biology	No	No
Last et al. (2011)	Australia	Yes	Syst	Distribution shift	No	No
Lloyd et al. (2012)	South Africa	No	Syst	Distribution shift	No	No
Ordines et al. (2018)	Spain	Yes	Hap	Distribution shift	Yes	Yes
Palacios-Salgado et al. (2014)	Mexico	No	Hap	Fish assemblage	No	No
Pita and Freire (2014)	Spain	Yes	Syst	Exploitation	No	No
Rizgalla et al. (2017)	Libya	No	Hap	Fish biology	Yes	Yes
Russell (1983)	New Zealand	No	Hap	Fish biology	No	No
Sbragaglia et al. (2020a)	Italy, Croatia	No	Syst	Distribution shift	No	Yes
Sbragaglia et al. (2021a)	Italy	No	Syst	Distribution shift	Yes	Yes
Schroeder and Parrish (2005)	USA	No	Syst	Fish assemblage	No	No
Ten Brink and Dalton (2018)	USA	No	Syst	Anthropogenic impacts	No	No
Tiralongo et al. (2018)	Italy	No	Hap	Non-indigeNous species	No	No
Welch et al. (2010)	Australia	No	Syst	Exploitation	No	No
Young et al. (2014)	Australia	Yes	Syst	Exploitation	Yes	No
Young et al. (2015a)	Australia	Yes	Syst	Exploitation	Yes	No
Young et al. (2015b)	Australia	Yes	Syst	Exploitation	Yes	No
Zapelini et al. (2017)	Brazil	No	Syst	Exploitation	No	No

The area of study is reported together whether the data was coming from recreational fishing trips (Tourn = no) or tournaments (Tourn = yes), and whether the use of the data was systematic (Use = Syst) or haphazard (Use = Hap). The research context has been listed highlighting together whether the data proceeded from photos/videos, or social media

fish populations (i.e., the emergence of fish populations that are more timid when exploited compared to unexploited populations of the same species; Arlinghaus et al. 2017b). For example, Sbragaglia et al. (2018) showed that Mediterranean fishes can differentiate spearfishers from snorkelers and adjust their flight initiation distances to be greater than the range of spearguns. Spearfishing may also influence other aspects of defensive behavior, such as pre- and post-flight behavior (Januchowski-Hartley et al. 2011;

Nunes et al. 2015; Bergseth et al. 2016), as well as diurnal hiding behavior (Côté et al. 2014). Moreover, flight initiation distance of fishes can decrease with depth (Stamoulis et al. 2019; Pereira et al. 2020), which suggests that spearfishing impact may decrease with increasing depth due to physical limitation of divers. Furthermore, a potential depth refuge could exist in deeper water, likened to a marine protected area with vertical boundaries, where larger fish persist in deeper waters out of the reach of spearfishing can help repopulate the shallower habitats over time (Lindfield et al. 2014).

These various changes in behavioral phenotypes of fishes may result in time and energy costs for individuals (Dill et al. 2003), and may also affect group behavior, with possible repercussions for fisheries and conservation strategies (Sbragaglia et al. 2021b). For example, there can be strong links between antipredator behavior and other functionally important behaviors (e.g., movement, feeding, mating) and the potential for community-wide dynamics and ecosystem-level consequences of recreational spearfishing. Changes in behavior due to protection may be transmitted outside protected areas, and although likely limited in both spatial and temporal reach, may increase susceptibility to recreational spearfishers (Januchowski-Hartley et al. 2013, 2014). The reduced boldness of fishes may be linked to reduced feeding rates on standard prey in fished areas (with spearfishing) relative to protected areas (Rhoades et al. 2019; Skinner et al. 2019). In particular, spatio-temporal activity patterns can be modified as expected from the "landscape of fear" hypothesis (Brown et al. 1999; Gaynor et al. 2019), but such effects specific to spearfishing are empirically difficult to test especially in mixed coastal fisheries. Ascertaining effects on other functionally important behaviors of targeted species will be an essential area of research to develop effective ecosystem-based management of both commercial and recreational fisheries. Behavioral changes may be used as indicators of spearfishing disturbance of fish population (Bergseth et al. 2016; Tran et al. 2016; Sbragaglia et al. 2018) and to inform associated conservation strategies (e.g., Berger-Tal et al. 2011), but the link to population dynamics is not always straightforward (i.e., behavioral changes do not always affect survival or reproduction; Gill et al. 2001). For example, species that show strong avoidance of spearfishers presence may be in less need of protection relative to those that do not (Gill et al. 2001). Additional study of the effects of recreational spearfishing on other functionally important behaviors and the functional role of targeted species will be important for understanding the individual, population, and community-level consequences of marine recreational spearfishing.

The ecological knowledge of recreational spearfishers

We retrieved 37 papers that used spearfishing for other scientific purposes (26 in a systematic way, and 11 in a haphazard way; Table 2). Interests spanned from understanding trends of fish populations (27%), tracking occurrence of non-indigenous species (19%), quantifying distributional range-shifts of species (16%), characterizing fish assemblages (16%), and analyzing general fish biology (11%; see other categories in Table 2). Ecological information has also been extracted from spearfisher-held underwater cameras in papers published after 2011 (30%; Table 2). Underwater videos actively recorded by recreational spearfishers may be useful for monitoring fish assemblages, analyzing fish behavior, and testing hypotheses at large spatial and temporal scales (Bulleri and Benedetti-Cecchi 2014). Additionally, the use of social media as a tool for passive data collection or interaction with spearfishers appeared in papers published after 2016 (13%; Table 2), with "*social media*" appearing as relevant nodes in the co-occurrence analysis (Fig. 4). Emerging digital approaches represent a promising tool for characterizing spatio-temporal distribution and dynamics of marine life, and the use of digital data can benefit from the high spatial dispersion of marine recreational spearfishers, and by accessing the information directly from digital platforms (Sbragaglia et al. 2021a; Lennox et al. 2022). However, operationalization of data-mining approaches from digital data is still ongoing, and future integration of machine learning and harmonized datasets could boost applications of these methods inside and outside academia (Lennox et al. 2022). Data from spearfishing tournaments have been used for gathering ecological knowledge (9 out of 37; Table 2), such as catch data providing information on marine fish communities over time (Mann et al. 1997; Pita and Freire 2014; Gledhill et al. 2015; Boada et al. 2017).

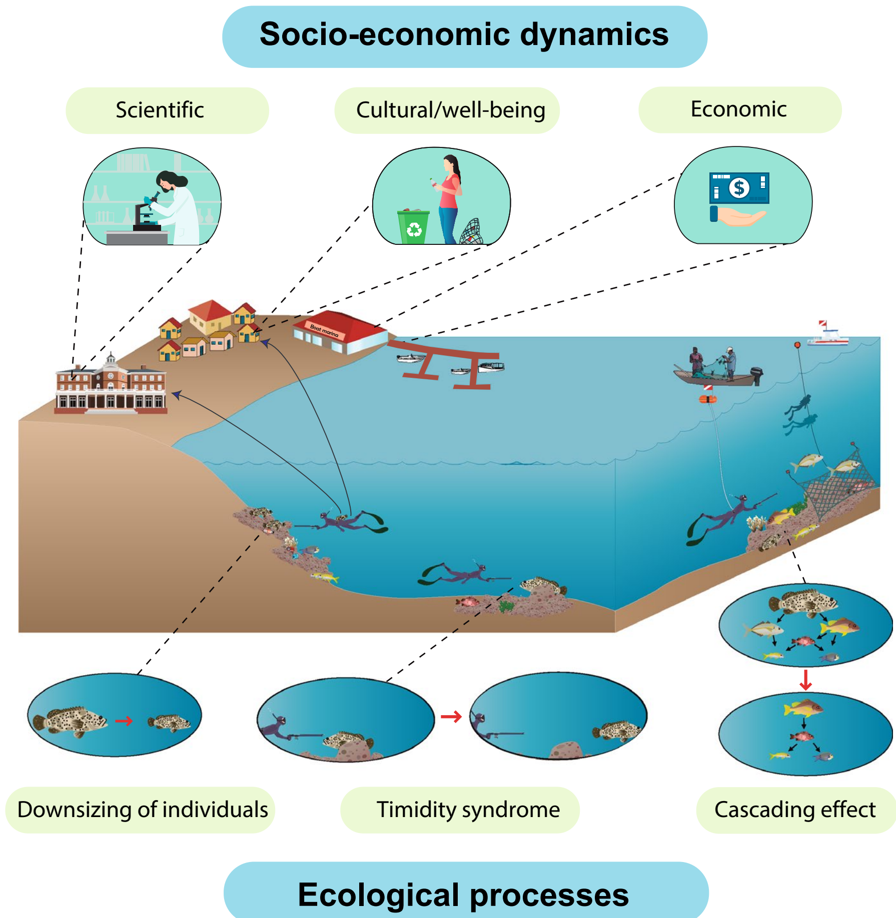

Fig. 5 Conceptual representation of the different processes involved in multidisciplinary research applied to marine recreational spearfishing. Socio-economic dynamics are presented at the top: contribution to scientific research ("The ecological knowledge of recreational spearfishers" section); social ("Social aspects" section) and economic ("Economic impact" section) aspects. Ecological processes are presented at the bottom; downsizing of individuals ("Changes in behavioral phenotypes of fishes" section); timidity syndrome ("Selectivity of recreational spearfishing and potential effects on marine ecosystems" and "Changes in behavioral phenotypes of fishes" sections); possible cascading effects at ecosystem level ("Changes in behavioral phenotypes of fishes" section). Symbols are courtesy of the Integration and Application Network (http://ian.umces.edu/symbols/)

Spearfishing tournaments may also be used to mitigate the invasion of non-native species such as lionfish, *Pterois volitans,* in the Atlantic Ocean (Barbour et al. 2011; Harris et al. 2019, 2020). Culling of lionfish by spearfishing appears to be one of the most effective community-led methods that might help mitigate the spread and ecological impacts of invasive lionfish (Malpica-Cruz et al. 2016). Indeed, most of the papers we identified using spearfishing for other scientific purposes were from the Caribbean Sea, where lionfish invasions are causing severe damage (Barbour et al. 2011). The interaction between spearfishing tournaments and biological invasions represents an important example to understand how synergies between spearfishing groups and conservation authorities can react and respond to complex ecological challenges.

In summary, the use of recreational spearfishers in scientific studies, combined with their time underwater, suggests that over time, experienced recreational spearfishers may develop a deep knowledge of habitat preferences, behavior and occurrence of targeted species which leads them to develop stewardship ethics as recently conceptualized for recreational anglers (Shephard et al., in press). Recreational spearfishing can directly (e.g., by spearfisher local ecological knowledge) or indirectly (e.g., by passive mining of digital data or tournaments) contribute to ecological understanding and conservation of marine ecosystems (e.g., Sbragaglia et al. 2020a; Foster et al. 2023). Such use may be encouraged, especially as voluntary bottom-up resource-conserving actions (Sbragaglia and Arlinghaus 2020), because they provide complementary and alternative information to costly institutional actions (Cooke et al. 2013; Fujitani et al. 2017; Arlinghaus et al. 2019). An overarching question is whether the ecological knowledge of recreational spearfishers differs from that of recreational anglers and other types of fishers, and how it can be integrated with other knowledge systems to better inform fisheries management (e.g., Lee et al. 2019).

Concluding remarks and future directions

We provide a multidisciplinary and global characterization of marine recreational spearfishing spanning the range of social, economic, and ecological dimensions as reported in the current literature (Fig. 5). Research interest in marine recreational spearfishing is increasing, but there are several key points to keep in mind for the future study and management of marine recreational spearfishing.

Recreational spearfishers may consistently differ from recreational anglers in their motivations and the human well-being generated by the fishing activity, though the demography of spearfishers (gender, race, and socioeconomic status) remains largely unstudied. Considering that recreational fisheries are complex adaptive social-ecological systems (Hunt et al. 2013; Arlinghaus et al. 2017a), differences within recreational fishing should be accounted for specifically in those situations where recreational angling and spearfishing are managed with different regulations and paradigms. We showed an increasing number of papers focused on understanding marine recreational spearfishing in the last decade, which could help to fill such knowledge gaps in the future.

Recreational spearfishers selectively target mid- to high-trophic level and mid- to high-vulnerability species (e.g., slow life history traits), which may exacerbate their ecological impact in comparison to other fishing methods (for example, triggering density-mediated or risk-mediated effects with consequent cascading effects; Baum and Worm 2009; Estes et al. 2011; Boaden and Kingsford 2015). This should be carefully evaluated with respect to other fishing methods considering recent technological development. For example, in terms of size selectivity, there are two aspects to consider when looking at ecological impacts on exploited fish population dynamics. Firstly, depending on the species, other fishing methods could potentially exert the same or even a stronger pressure on larger individuals and vulnerable species (e.g., such as the case of *Dentex dentex* in the Mediterranean Sea; Marengo et al. 2015; Sbragaglia et al. 2020b). Management in these contexts requires appropriately assessing the relative impacts of fishing methods in light of recent fishing technological innovations (Cooke et al. 2021). Secondly, other fishing methods could potentially exert stronger pressures on immature individuals compared to recreational spearfishing (Frisch et al. 2008). Therefore, predictions of ecological impacts in terms of species-specific population productivity should consider fishing mortality of larger individuals with greater reproductive potential, as well as fishing mortality of immature individuals (Barneche et al. 2018; Ahrens et al. 2020; Marshall et al. 2021). From an ecosystem perspective, there is little empirical evidence on whether the potential impact of recreational spearfishing differs from that of other fishing methods, and this deserves specific research attention in the future.

There is strong evidence that spearfishing increases wariness of exploited fish populations. Human-induced changes of behavior have been shown in response to several fishing techniques spanning from active to passive and from recreational to commercial fishing gear (Arlinghaus et al. 2017b; Diaz Pauli and Sih 2017; Sbragaglia et al. 2021b). However, what is unique in behavioral interactions between spearfishing and fish is that fish wariness is directly linked to underwater human presence (Samia et al. 2019), and that antipredator responses to spearfishers may mimic responses to natural predators as recently demonstrated for snorkelers (Asunsolo-Rivera et al. 2023). The possible consequences of human-induced fish behavioral changes should be carefully quantified from an ecosystem perspective (Gaynor et al. 2019; Wilson et al. 2020; Rahman and Candolin 2022), particularly linking changes in anti-predator behavior to changes in other functionally important behaviors (e.g., movement, feeding, mating). In particular, cumulative impacts on consumptive (Arlinghaus et al. 2016) and non-consumptive (Geffroy et al. 2015; Asunsolo-Rivera et al. 2023) activities should be accounted for in population, community and ecosystem dynamics. This would enable a comprehensive understanding of spearfishing impacts relative to human-induced effects and inform effective management regulations for sustainable fishing, tourism, and conservation.

Alongside possible ecological impacts of spearfishing, there is also evidence suggesting that recreational spearfishing can contribute to advances in marine ecological knowledge. Growing research relationships and networks between recreational spearfishers and researchers can also help to build diverse knowledge systems to navigate future management scenarios of increasing protection of coastal areas and management of recreational spearfishing, which is an important topic (supported by "*marine reserve*" appearing as important nodes in the co-occurrence analysis; Fig. 4). In this context, the inclusion of recreational spearfishers in participatory processes (e.g., within the framework of co-management systems) may be advisable for two main reasons. Firstly, spearfishers can provide early warning and knowledge about conservation problems where existing monitoring data are insufficient (Gledhill et al. 2015; Zapelini et al. 2017; Sbragaglia et al. 2020a; Middleton et al. 2021; Foster et al. 2023). Secondly, fostering an inclusive process could reduce conflicts and stimulate cooperation, trust, proactive behaviors, and even change existing misperceptions such as those related to systematic harvesting of large, long-lived, and slow-growing species (Gledhill et al. 2015; Horta e Costa et al., 2022; see also "Changes in behavioral phenotypes of fishes" section). In this context, considering that spearfishers are usually younger than other groups of recreational fishers, it is advisable to engage them using social media and digital methods (Allison et al. 2022; Lennox et al. 2022), which could be more effective than traditional engagement strategies. A significant proportion of Australian and Mediterranean recreational spearfishers support self-regulatory actions (Young et al. 2014; Sbragaglia et al. 2016) and perceive that no-take marine protected areas are important tools for the conservation of marine ecosystems (Mann et al. 1997; Assis et al. 2018). Inclusive, participatory and collaborative management is important in the current scenario of increasing protection of marine coastal areas for achieving biodiversity conservation, developing an inclusive blue economy, and increasing acceptance of new regulations (Di Franco et al. 2020; Grorud-Colvert et al. 2021; Horta e Costa et al., 2022). Beyond daily bag limits and size limits, possible alternative management strategies could consist of periodic spatial and/or temporal closures (Goetze et al. 2018; Carvalho et al. 2019). In particular, the wariness of fish could be a good indicator of ecological disturbance of marine recreational spearfishing and could be used to apply periodic spatial and/or temporal closures (Goetze et al. 2017). Thus far, such approaches have mainly been implemented in subsistence fisheries, but they could similarly be applied to recreational spearfishing.

The present and future of recreational spearfishing are facing a change in perceptions, beliefs, and behavior of its practitioners, all of which could support the future sustainability of the sector. For example, the attitudes of some recreational spearfishers are already changing from being a group exclusively interested in "adventure-seeking hunting" to a group that is interested in "sea-appreciating hunting" (i.e., towards sharks and rays on the Great Barrier Reef, Whatmough et al. 2011). Such changes in attitudes are also suggested by an increase in the conservation awareness of recreational spearfishers in the Mediterranean Sea (Sbragaglia and Arlinghaus 2020). Scientists and managers would benefit from encouraging this ongoing transition, towards the spreading of best practices driven by recreational spearfishers that exemplify these new attitudes of marine stewardship. This could be a triggering factor to successfully navigate toward the sustainable development of recreational spearfishing in the future, as has been demonstrated for recreational angling (Fujitani et al. 2017). We hope this review will help to stimulate such transitions and encourage future research on marine recreational fisheries.

Acknowledgements We are grateful to Marta Coll, Arnau L. Dedeu, Nikolas Michailidis for their help. We acknowledge Marco Bardi for providing some of the pictures used in Figure 1. VS was supported by a "Juan de la Cierva Incorporación" (IJC2018-035389-I), and he is now supported by a "Ramón y Cajal" research fellowships (RYC2021-033065-I) granted by the Spanish Ministry of Science and Innovation. SV and PP are supported by the Xunta de Galicia (RECREGES I and II projects under Grants ED481B2014/034-0 and ED481B2018/017), Grupo de Referencia Competitiva GI-2060 AEMI, under Grant ED431C2019/11), and Fundación Biodiversidad, Ministerio para la Transición Ecológica y el Reto Demográfico, Gobierno de España (SICORE and GT PMR projects). VJG received a postdoctoral grant (#2017/22273-0) from São Paulo Research Foundation (FAPESP). MR would like to acknowledge Portuguese national funds from FCT—Foundation for Science and Technology through projects UIDB/04326/2020, UIDP/04326/2020 and LA/P/0101/2020. MR would also like to acknowledge FCT funding through a postdoctoral grant (SFRH/BPD/116307/2016). JACCN thanks to Meros do Brasil Project sponsored by Petrobras. FJH is supported by a Sêr Cymru European Regional Development Fund Fellowship (80761-SU-135). RA was supported by the German Federal Ministry of Education and Research (Grants 01LC1826E and 033W046A). ML is supported by the Agencia Nacional de Investigación e Innovación (ANII, POS_EXT_2020_1_165362). This work acknowledges the 'Severo Ochoa Centre of Excellence' accreditation (CEX2019-000928-S).

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature.

Data availability The full list of papers used for the systematic review is available as a supplementary table.

Declaration

Conflict of interest The authors declare no conflicts of interest.

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