Foreword

The oceans are facing increasing pressure related to water warming, acidification, pollution, overexploitation and illegal activities, which generate biodiversity loss and ecosystem degradation, placing at risk the provision of goods and services. In order to preserve healthy and resilient marine ecosystems, adaptive scientific tools for the sustainable management of resources are required, as agreed in the Agenda 2030 (UN 2015). Key elements for sustainable social and economic progress worldwide were identified in the Agenda. Under this framework, with humanity's aim to move more efficiently and effectively towards these goals, the UN has designated the period 2021-2030 as the Decade of Ocean Science for Sustainable Development (UN 2017). The focus is placed on i) maintaining a clean, healthy, safe and resilient ocean, ii) developing tools to predict future changes in marine conditions and their impact on society, iii) ensuring the sustainable exploitation of resources, especially food resources, and above all, iv) ensuring transparency and availability of information.

Marine fisheries provide food of high nutritional value for millions of people and are an important economic driver on all continents (FAO 2022). Particularly important is the role that small-scale artisanal fisheries play in the food systems, livelihoods, culture and environment of regions and communities, which are highly vulnerable to environmental and economic perturbations (Chuenpagdee 2011). For this reason, the UN declared 2022 the International Year of Small-scale Fisheries and Aquaculture (UN 2018), with the intention of promoting sustainable small-scale fisheries that ensure food security and poverty eradication.

The current state of fish stocks is alarming, 34% of them being currently exploited at unsustainable levels and 60% at the maximum sustainable level (FAO 2022). It has been predicted that, if current fishing effort is maintained, most fisheries will collapse by 2048 (Worm et al. 2006). While total catches have stabilized since the late 1990s, when they reached the historic maximum, the lack of data from some fisheries and the existence of illegal and unregulated fishing call into question predictions about the future of fisheries (Pauly and Zeller 2015). Pauly and Zeller (2015) estimate global catches at over 100 million t, well above the officially reported 80 million t. Therefore, it is imperative to implement suitable management measures, improve the collection of fisheries information, and expand the knowledge of exploited organisms and marine ecosystems in order to revert to current situation of fisheries exploitation and make them sustainable over time.

Marine ecosystems and fisheries in the Iberian Peninsula and Latin America (i.e. Ibero-America), are no exception to the vulnerabilities and challenges of global fisheries. The wide geographical distribution of the Ibero-American regions entails a high diversity of marine ecosystems (Seeliger and Kjerfve 2013, Cortes et al. 2020), from coral reefs to circumpolar ecosystems, as well as a great diversity of fisheries (Rivero-Rodriguez and González-Fernandez 2021), from the largest industrial fisheries in Peru that exploit pelagic species to the artisanal fisheries in coastal areas of the Caribbean Sea. There is also great variability in the fisheries features and incomes among countries, which hampers the development of appropriate methods for assessment and management (Fig. 1). Fishing in Ibero-America is an important economic activity, generating employment and income for many communities, with more than 1.5 million people working directly in this activity in Latin America and the Caribbean alone (FAO 2022). Fishing activity in Ibero-America focuses on a great diversity of species and ecosystems (Rivero-Rodriguez and González-Fernandez 2021). In fact, this region has some of the largest marine ecosystems on the planet, such as the Humboldt Current System in Chile, Peru and Ecuador, which supports the largest small pelagic fishery in the world, the Patagonian Shelf in Argentina and Uruguay, where one of the most productive demersal fisheries in the world takes place, and the Southern Shelf in Brazil.

There is no facilitating organization in the regions to achieve the objectives of conservation, management and sustainability through coordinated research and assessment of fishery resources, which are often exploited by different countries, including those outside the Ibero-American regions. A particular concern is the lack of knowledge about the resources exploited by artisanal fleets (Olivei-

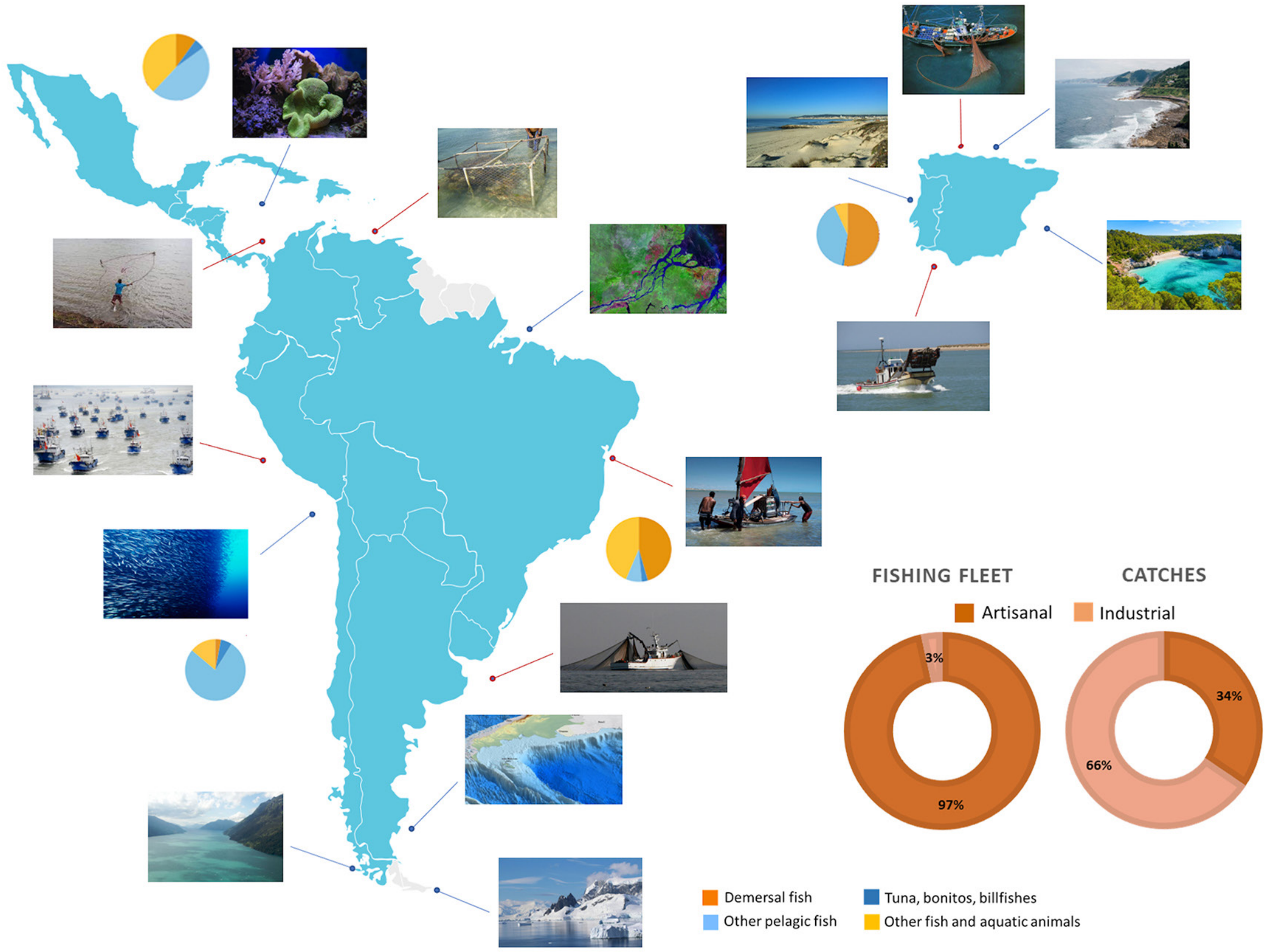

Fig. 1. – Illustrations of the diversity of ecosystems (blue lines) and fisheries (red lines) in Ibero-America. The pie charts represent the major species groups caught in the main Ibero-American fishing areas (FAO 2022). The ring diagrams represent the proportion of vessels and catches from the artisanal and industrial fisheries for the global region of Ibero-America (Pauly and Zeller 2015). Fishing fleet data come from the National Fisheries Statistics of the main fishing countries in the region (Argentina, SPM 2019, Brazil, SISRGP, 2021, Chile, SERNAPESCA 2021, Spain, Pascual-Fernandez et al. 2020 and SGP 2021, Mexico, CONAPESCA 2017 and INEGI 2021, Peru, PRODUCE 2021). Image copyright: Sam Beebe, Ivan Blanco Vilar, Pawel Kazmierczak-Shutterstock, Marco Ramerini, Vitor M. Cabral da Olive, Otávio Nogueira (https://www.meganoticias.cl), Diego Delso, El Estrecho Digital, Agencia EFE and Wilfedor.

ra-Leis et al. 2019), despite its great potential for reducing hunger and malnutrition, preserving biodiversity and natural resources and mitigating the impact of climate change.

Research in fisheries ecology and biology contributes greatly to meeting the challenges of today`s fisheries. Fish stocks are characterized by their own life history, mainly determined by the traits defining the reproductive potential, growth and natural mortality of individuals and populations (Stearns 1977). These traits are endogenous factors determining the stock dynamics, though stocks are also affected by environmental factors, including fishing (Rochet 1998). For all these reasons, added to the fact that ecological relationships between organisms determine the structure and functioning of the ecosystems, ecosystem-based fisheries management is fundamental for evaluating and regulating the impact of the fishing activity on marine populations, habitats and ecosystems, and ultimately on society (Fig. 2).

Scientific production in the field of fisheries ecology in the Ibero-American regions is extensive, although not always known and accessible. Since its foundation in 2009, the Ibero-American Research Network for the Sustainable Use of Fisheries Resources (RED INVIPESCA) has been working to strengthen Ibero-American fisheries research through collaboration and knowledge exchange between leading institutions and researchers in the field (Rivero-Rodriguez and González-Fernandez 2021). This mission is addressed through various activities, including the Ibero-American Symposium on Reproductive Ecology, Recruitment and Fisheries (SIBECORP), of which five editions have already been celebrated in Vigo (Spain) in 2009, Mar del Plata (Argentina) in 2012, Puerto de Galinhas (Brazil) in 2015, Iquique (Chile) in 2018 and Santa Marta (Colombia) in 2021. This special issue of Scientia Marina brings together a selection of papers presented at the last edition of SIBECORP in Santa Marta. The programme of this edition, held in hybrid format (face-to-face and online) owing to the COVID-19 pandemic, included four pre- and post-symposium courses, three keynote talks, 48 oral presentations, 48 posters and two workshops.

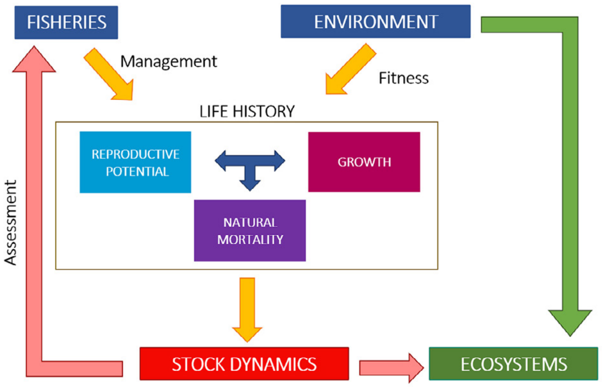

Fig. 2. – Diagram of the main endogenous and exogenous factors involved in the dynamics of exploited fish stocks for consideration in fisheries biology, ecology and management studies.

In contrast to previous editions that were more focused on fish, the fifth SIBECORP included noteworthy communications on reproductive ecology and management of exploited invertebrates. For the first time, some presentations incorporated social and economic perspectives of fisheries, which are essential for a fair and effective management. The symposium was organized around four thematic sessions: i) reproductive strategies of aquatic organisms, ii) reproductive potential and resilience, iii) recruitment and reproductive success and iv) reproductive ecology and fisheries management. The following sections are a review of the main conclusions reached after each session.

Reproductive strategies of aquatic organisms

Exploited aquatic organisms display a large variety of reproductive strategies and associated traits (Saborido-Rey 2016) such as gender, breeding and mating systems, gametogenesis and embryonic development, mode of fertilization, spawning pattern, parental care, distribution of energy resources and behaviour, all of them often showing temporal and spatial variation and defining the reproductive tactics adopted by the different species (Stearns 1992). This variability leads to strong plasticity in life-history traits such as maturation, fecundity and egg size, viability of offspring, growth pattern associated with reproductive dynamics, and mortality (or survival). All these traits define the reproductive potential and govern the annual variability in egg production, which in turn would explain changes in recruitment and reproductive success (see below).

The amount of energy that an individual allocates for growth and reproduction depends on its genetics and physiology, as well on environmentally driven factors. This energy must be balanced in a specific growth and reproduction dynamics and in trade-offs at different time scales of an individual organism: lifetime, annual, intra-seasonal and diel. The lifetime scale refers to attaining sexual maturation, a critical decision that will modify individual fitness, reproductive effort; it has its ultimate goal in egg production and spawning dynamics as a measure of reproductive success. Thus, assessing changes in maturation is an essential goal in fisheries management, as fisheries drastically modify size and age at maturation. They may even may induce adaptive changes and changes in maturation alter stock dynamics, sometimes leading to drastic consequences such as stock collapse (Olsen et al. 2004). Lojo et al. (2022) analysed the temporal variability of size at maturity (L_{50}) in European hake (*Merluccius merluccius*), concluding that L_{50} is a good indicator for predicting future population dynamics. The large plasticity in life-history traits implies the existence of local and regional adaptations that will lead to overexploitation if not properly considered in fisheries management. Macal-Lopez et al. (2022) estimated reproductive parameters of the snapper *Lutjanus griseus* on the continental shelf of the Yucatan Peninsula, Mexico, and compared them with other shelves and insular regions in the vicinity, providing data fundamental for stock assessment.

While temporal variation of reproductive traits has often been analysed, spatial variation has received less attention. The spatial patterns of many reproductive traits are known to show great variability, which is being exacerbated by climate change, especially in pelagic fish. Moreno and Claramunt (2022) report that the annual variation in the location and extension of the spawning area of the anchoveta *Engraulis rigens* in Chile shows an interesting strategy of density-dependent use of space related to female size and abundance. However, it is currently difficult to ascertain whether observed spatial patterns in reproductive traits are due to phenotypic plasticity, local adaptation or both, and to determine the role of climate change. Domínguez-Petit et al. (2022b) show a great latitudinal variation in several biological parameters of Atlantic chub mackerel (*Scomber colias*) within a relatively small area, including size at maturity and spawning season. The different strategies observed seem to be related to the thermal tolerance of the subpopulations studied.

Because reproduction has a cost in terms of energy, which may be very high, there is always a trade-off between the number of reproductive events and reproductive outputs (e.g. fecundity and egg size) that the individual can afford. The ultimate goals of reproductive effort are egg production and spawning dynamics as a measure of reproductive success, so fecundity is often considered one of the most important components of a reproductive strategy (Lowerre-Barbieri 2009). Furthermore, studies on fecundity in aquatic organisms are still rare, and long time series of fecundity are usually not available (Tomkiewicz et al. 2003). Fecundity studies are critical for understanding the temporal variation in reproductive potential and how maternal effects can interact with fecundity, as shown for the Acadian redfish *Sebastes fasciatus* (González-Carrion and Saborido-Rey 2022).

In summary, there is a critical need for precise knowledge on the reproductive strategies of the managed populations, on the temporal and spatial variation of these strategies, and on life-history traits. These variations have a profound impact on reproductive potential, resilience, recruitment and reproductive success that must be considered in fisheries management, as discussed in the following sections.

Reproductive potential and resilience

Since the concept of reproductive potential of a stock was coined as the capacity to produce viable offspring that are recruited to the fishery (Trippel 1999), many studies have been carried out to understand the endogenous factors, beyond genetics, that regulate this potential (Nissling et al. 1998, Berkeley et al. 2004, Macchi et al. 2018). These factors are called parental effects and refer to the influence that the phenotype and environmental conditions in which individuals develop have on the phenotype of their offspring (Bernardo 1996). To date, the study of parental effects in aquatic organisms has been dominated by research on maternal effects (derived from females), with the role of males being limited to gene transmission (Shama et al. 2014, von Siebenthal et al. 2009). However, an increasing number of studies have demonstrated the existence of paternal effects in aquatic organisms ranging from the direct influence of paternal attributes on offspring quality (Rideout et al. 2004) to the influence of parental behaviour on offspring survival (Stein and Bell 2014) and the impact of the environment on male reproductive success (Beirão et al. 2011, López-Galindo et al. 2019, Thomas et al. 2015). These relationships are not always direct. For example, González-Carrion and Saborido-Rey (2022) report maternal effects on the quantity and quality of eggs of *S. fasciatus* from the Northwest Atlantic. However, these authors observed no effect of maternal attributes on larval characteristics, and questioned whether the maternal effects have a real impact on recruitment of this species. This study also suggests that the assumption that all spawning biomass has the same reproductive potential regardless of the parental attributes and the environmental conditions to which spawners are exposed is insufficient, as there are numerous and complex environment-stock interrelationships that define the long-term reproductive success of a population.

This holistic and transgenerational view is captured in the concept of reproductive resilience coined by Lowerre-Barbieri et al. (2017). The reproductive resilience of a stock is determined by the characteristics of the population's reproductive-recruitment system and the environmental and ecological context in which the population develops. In this theoretical framework, reproductive success is an individual parameter that gives rise to density- and fitness-dependent feedback loops, which act at the population level to maintain reproductive success over time and determine the resilience of the population to external perturbations (Lowerre-Barbieri et al. 2017).

Knowing the spatial structure of the stock is fundamental for determining its reproductive resilience, since this determines the ecological context and the genetic flow between the components of the population. Domínguez-Petit et al. (2022b) present the example of *Scomber colias*, an expanding species in the Northeast Atlantic whose population structure is not yet known, but which shows a gradient in its biological parameters (size, age, condition and maturity) from the core of its distribution in NW African waters to the northern limit of distribution in the Cantabrian Sea, which could lead to differences in the reproductive potential of the species in each area. These authors also postulate the existence of a possible mixing zone in the Gulf of Cadiz, where individuals from the Mediterranean population would converge with those from the Atlantic, demonstrating that studies at different spatial and temporal scales are necessary to understand the functioning of the reproductive-recruitment system.

The study of reproductive resilience is key for a suitable management of fisheries, since it allows us to quantify the sustainability of exploited stocks in the medium and long term under different environmental and exploitation scenarios; however, to achieve this, good quality basic biological information is required. Especially important is the work focused on species for which there is hardly any information, many of which have an important ecological role, inhabit areas sensitive to anthropogenic impact and are exploited by small-scale artisanal or recreational fisheries of great social and economic importance for the communities that depend on them. This is the case of the grey snapper (*Lutjanus griseus*), an important fishing resource in the Atlantic coast of USA and the Gulf of Mexico, whose reproductive traits may vary depending on the area they inhabit. Macal-Lopez et al. (2022) analyse the reproductive strategy of this species in the Yucatan Peninsula, confirming that it shows the typical reproductive pattern of snappers distributed on continental shelves or in shallow water areas. In addition, they highlight the importance of having a good monitoring programme for the species and standardizing the methods for estimating reproductive parameters, as well as considering the reproductive and feeding behaviour of individuals in order to design a suitable monitoring programme.

Recruitment and reproductive success

Stearns (1992) defined reproductive success as the probability that offspring will survive to reproductive age based on egg production, fertilization success and survival of the reproductive output. While in early life stages the environment plays an important role in egg and larval mortality, survival in this period is modulated by parental effects (Domínguez-Petit et al. 2022). The bigger-is-better hypothesis (Green 2008, Barneche et al. 2018) suggests that larger females produce more and larger eggs from which larger larvae, which are more likely to survive, will hatch (McCormick 2006). It is not just a matter of size: the age and condition of the broodstock also influences the fitness of the offspring (Gall 1974, Marteinsdottir and Steinarsson 1998, Green 2008). This is because larval behaviour and physiology are related to size (Hunter 1981). Similarly, in species such as Atlantic cod (*Gadus morhua*), the size of spawning males has been found to influence fertilization success (Bekkevold 2006) and survival of embryos and larvae (Trippel et al. 2005); while in other species where paternal care of the offspring exist, growth and survival of offspring are related to paternal attributes (Divino and Tonn 2008, Green and McCormick 2005).

Reproductive success depends not only on the quantity and quality of reproductive output, but also on the selection of suitable spawning habitat, i.e. it matters not only how much, but also when and where the fish reproduce. In this regard, it has been observed that female size, closely related to age, affects egg density and thus egg distribution and transport to suitable breeding areas (Kjesbu et al. 1992), while the age of spawners determines the onset and duration of the spawning season (Kjesbu et al. 1990, Macchi et al. 2004) and the ability to reach suitable spawning sites (Macchi et al. 2005, Petitgas et al. 2006). The timing and location of spawning determine the environmental conditions in which offspring must develop, and in the early life stages of fish these factors are key to the survival and thus the reproductive success of the entire population (Marshall 2016). Indeed, in species such as Atlantic cod (Marteinsdottir and Thorarinsson 1998) and Norwegian herring, *Clupea harengus*, (Lambert 1990), recruitment has been shown to be positively correlated with the proportion of older females. Moreover, in species such as *Sander viterus*, populations with low age diversity are more likely to experience mismatches between spawning and optimal environmental conditions, leading to low recruitment (Shaw et al. 2018). This is particularly important in the context of global warming that the oceans are experiencing, as offspring survival will depend on the ability of parents to match adequate spawning location and timing under this changing environment. Puerto et al. (2022) report an expansion of the spawning area of the skipjack tuna, *Katsuwonus pelamis*, in the western Mediterranean, likely associated with the warming of these waters that has been detected in recent decades. This expansion could impact on other tuna species dynamics in the western Mediterranean, which now have to share their spawning area with skipjack tuna.

In summary, recruitment is largely determined during the larval stage (Leggett and Deblois 1994), whose survival is intimately linked to parental effects that ultimately define the reproductive success of the stock. Assessing the factors that determine the reproductive success of a stock is both complex and essential for sustainable fisheries management, as it would reduce uncertainty in recruitment predictions and provide a better insight into population dynamics. A promising tool in this field is the RNA/DNA ratio as an index of larval condition. Using this molecular index, Diaz et al. (2022) demonstrated that the North Patagonian Frontal System is a favourable nursery area for anchovy (*Engraulis anchoita*) and Argentine hake (*Merluccius hubbsi*) and is therefore key in the recruitment in these two commercially important species.

Reproductive ecology and fisheries management

The reproductive ecology of species explains the mechanisms underlying the reproductive success of stocks, and hence their ability to sustain themselves over time. Fisheries are based on the capacity of these populations to maintain themselves at sufficient levels to ensure the profitable capture of individuals without compromising the viability of the population. The ultimate goal of fisheries management is to ensure exploitation levels that guarantee long-term sustainability of both the population and the economic activity.

Fishing activity influences the reproductive success of stocks due to the strong selective impact on populations segments, e.g. large versus small individuals, females versus males, spawners versus juveniles, etc. In turn, the reproductive success of stocks determines the amount of fish available for fishing (Lowerre-Barbieri et al. 2017). In addition, environmental factors and the other species that sharing the ecosystem with the exploited species also impact on their reproductive success (Lowerre-Barbieri et al. 2017). This is the basis of the ecosystem approach to fisheries management (EAFM), which aims to manage marine resources from a holistic perspective, considering the impact of the fishery on the whole ecosystem, including biodiversity (FAO 2003). The EAFM must consider abiotic and biotic components of ecosystems, including human impacts (Garcia and Cochrane 2005) and aim to maintain exploited ecosystems in a healthy, productive and resilient state so that they can provide the services that humans need.

Nursery areas and their associated biodiversity are essential within the EAFM framework, as they contribute to understand the life cycle parameters of fisheries resources (including stock structure, growth, maturity, reproduction, recruitment, mortality and spawning areas and times) and helps to achieve an efficient fisheries management (Hilborn and Walters 1992), while allow protecting and conserving the existing ecosystems (Paramo et al. 2020), e.g. by implementing protected breeding areas, fishing bans, monitoring programmes and conservation strategies, among other management measures.

Knowledge of reproductive ecology, which is the focus of SIBECORP, is still quite limited in many exploited species, especially those targeted by artisanal fisheries, limiting the development and implementation of the EAFM.

The manuscripts published in the present special volume provide important information on the mechanisms that explain the reproductive success of exploited marine species, helping to improve their management. These studies are based on very diverse research fields such as physiology and bioenergetics (Pauly and Liang 2022), the analysis of spatio-temporal changes in reproductive parameters and parental effects (Domínguez-Petit et al. 2022b, Lojo et al. 2022, Macal-Lopez et al. 2022), and the temporal variation of spawning area location and extension (Moreno and Claramunt 2022, Puerto et al. 2022), in addition to relevant methodologies (Diaz et al. 2022, González-Carrión and Saborido-Rey 2022).

CONCLUSIONS

Fisheries in the Ibero-American region are among the most diverse and productive on the planet, and they contribute significantly to food security, poverty alleviation, development and the stability of rural and coastal communities. However, they face major anthropogenic risks (climate change, pollution, illegal and unregulated fishing and overexploitation), aggravated by a lack of knowledge on the ecology and reproductive potential of many of the exploited species, which in turn determine the resilience of the stocks to external disturbances.

Throughout the different editions of the Ibero-American Symposium on Reproductive Ecology, Recruitment and Fisheries (SIBECORP), the Ibero-American Research Network for the Sustainable Use of Fisheries Resources (RED INVIPESCA) has brought together scientists with expertise in fisheries ecology and assessment in order to identify the main knowledge gaps and needs for future research to implement sustainable management of fisheries resources in the region. To this end, the five editions of SIBECORP have promoted the dissemination of research carried out in the region around four fundamental pillars of fisheries ecology: the study of the reproductive strategies of exploited species; the quantification of reproductive potential and the causes of its variation as a key aspect of reproductive resilience; the influence of reproductive potential on reproductive success and recruitment to the fishery; and the development of management measures to preserve reproductive potential.

Despite the significant progress made in this area, reflected partially in the papers selected for this publication, there is still much work to be done in the region. We must expand and update the knowledge we have on the reproductive potential of exploited species and thoroughly revise globally accepted hypotheses that have proven to be invalid, as is done by Pauly and Liang (2022). These 13 years have only reinforced the idea that forums such as the INIVPESCA Network and the SIBECORP are needed to create a solid scientific basis on which to build a sustainable management system for Ibero-American fisheries to guarantee the achievement of the Sustainable Development Goals of the 2030 Agenda.

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