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PERSPECTIVE

Linking the scientific knowledge on marine frontal systems with ecosystem services

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Abstract Primary production hotspots in the marine environment occur where the combination of light, turbulence, temperature and nutrients makes the proliferation of phytoplankton possible. Satellite-derived surface chlorophyll-*a* distributions indicate that these conditions are frequently associated with sharp water mass transitions named "marine fronts". Given the link between primary production, consumers and ecosystem functions, marine fronts could play a key role in the production of ecosystem services (ES). Using the shelf break front in the Argentine Sea as a study case, we show that the high primary production found in the front is the main ecological feature that supports the production of tangible (fisheries) and intangible (recreation, regulation of atmospheric gases) marine ES and the reason why the provision of ES in the Argentine Sea concentrates there. This information provides support to satellite chlorophyll as a good indicator of multiple marine ES. We suggest that marine fronts could be considered as marine ES hot spots.

Keywords Argentine Sea · Ecosystem services · Marine fronts · Satellite chlorophyll · South Western Atlantic

INTRODUCTION

Over the course of history, the ocean has supported the social development of human groups. By providing food, materials and communication, the oceans have allowed humans to spread all over the planet. The oceans stimulated the curiosity of early navigators, merchants, fishermen and adventurers, played the role of muses for artistic disciplines from visual arts to literature, challenged and motivated naturalists and scientists, and justified wars and territorial conflicts (Kurlansky 1998; Duarte 2010). Today, over 50% of the world human population lives within 200 km from the coast (28% lives closer than 100 km, Kummu et al. 2016). Despite the strong and long-lasting connection between human development and the oceans, marine systems still pose many relevant unanswered questions and knowledge gaps (Duarte et al. 2015).

Ocean science research is challenged by logistic and technological requirements that involve a high economic cost; this has delayed both, the improved understanding of physical, chemical and biological processes and the potential benefits that humans may obtain (Townsend et al. 2018). This deficiency is especially relevant given the growing demand for marine resources, as well as their intense and expanding exploitation posing a significant risk of altering marine ecosystem functioning (Weatherdon et al. 2016). In addition, climate change is also affecting marine life by modifying physical and chemical properties of the ocean (Poloczanska et al. 2016). For instance, it is predicted that due to climate change the global ocean will be warmer, less alkaline and less oxygenated, and will be less capable to absorb atmospheric gases (Rhein et al. 2013). Under this scenario, ocean sustainable management poses a serious challenge.

Sustainability and conservation of marine environments should be a common concern of stakeholders (e.g. fishermen, nongovernmental organizations, governmental and intergovernmental agencies involved in the management of natural resources). However, as some stakeholders have interests that are opposed, or perceived as opposed, there is a stringent requirement to conciliate and integrate the

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different points of view to generate successful environmental policies (Cáceres et al. 2015). It is in this context that several questions arise: how to conciliate antagonistic environmental, social and economic demands? What benefits, besides fishery production, are provided by the sea? What are the social consequences of management alternatives? Traditional approaches to ocean management and conservation, such as natural resource management and creation of marine-protected areas do address these questions, but often fail to integrate social and ecological dimensions. This integration may come from the Ecosystem Services (ES) approach, which focuses on the multiple benefits that humans obtain from ecosystems, considering ecological as well as social and economic dimensions, and providing an integrative framework to design and implement management tools (MEA 2005; Fisher et al. 2009).

The ES approach was initially developed for terrestrial environments and adopted for coastal marine ecosystems (Barbier et al. 2011). However, its application in marine systems beyond the coast has been difficult (Cognetti and Maltagliati 2010; Townsend et al. 2018). For instance, though people in coastal areas are strongly tied to the sea, humans do not inhabit the open ocean; therefore, there is a temporal and spatial uncoupling between provision of services by the ocean and their use by people on land, hampering the perception of these services. Most studies on marine ES have focused on functional features (e.g. Armstrong et al. 2012; Thurber et al. 2014) with few analyses including social dimension issues, such as economic valuations and assessments of the success of management policies (e.g. the Baltic Sea, Sagebiel et al. 2016).

The apparent homogeneity of the open ocean hides the existence of strong spatial contrasts in the distribution of resources and other environmental conditions. One of the most conspicuous large-scale manifestations of heterogeneity is the distribution of chlorophyll-*a* as seen through satellite images (Fig. 1). These images are useful to evaluate phytoplankton biomass distribution, and therefore, to identify primary production hotspots in the ocean. In these areas, a favorable combination of light, turbulence, temperature and nutrients may initiate and sustain phytoplankton blooms. These conditions, and the associated primary production, are particularly conspicuous in marine fronts (Fig. 1a, Acha et al. 2015). These three-dimensional structures are observed at the encounter of water masses with different characteristics that are typically associated with relatively sharp changes in temperature and/or salinity (Belkin et al. 2009; Acha et al. 2015). By modulating the vertical flux of nutrients, relatively intense vertical velocities near marine fronts may lead to enhanced primary production (e.g. Pollard and Regier 1990). In turn, primary production is linked to top-down and bottom-up processes propagating the heterogeneity onto other ecosystem levels, processes and components (Falkowski et al. 1998; Benoit-Bid and NcManus 2012). In this sense, several studies on marine fronts show marine consumers and biogeochemical cycles linked to high primary production areas (Woodson and Litvin 2015; Acha et al. 2015). For instance, marine mammals, turtles, birds and fish are coupled to primary production through trophic interactions (e.g. Mann and Lazier 2006); and, the large amount of phytoplankton photosynthesizing in marine fronts leads to increased CO_2 uptake from the atmosphere through the so-called biological pump (Takahashi et al. 2002).

Furthermore, several studies present evidence that certain types of fisheries are linked to marine frontal areas, and hence to primary production hotspots. For instance, the alternation of sardine-anchovy regimes and salmon production in the California current is clearly correlated to marine frontal areas (Woodson and Litvin 2015). In a global analysis, Chassot et al. (2010) demonstrated that at the scale of Large Marine Ecosystems primary production determines fisheries catches.

Given the social and economic importance of fisheries, a large effort has been dedicated to generate useful indicators of fish abundance. For instance, bathymetry and hydrodynamics have been used as indicators for some fisheries in different habitat types such as Arctic shelf waters (Bergstad et al. 2018), tropical regions (Lembke et al. 2017) or abyssal environments (Leitner et al. 2017), but data are scarce for many regions, especially for those located in remote areas and/or within economic zones of less wealthy countries; thus, ocean dynamics are mostly based on models that are updated as data become available (e,g. O'dea et al. 2012). However, bathymetry and hydrodynamics may not be enough to predict other marine ES nor useful for all fisheries.

Though provision of seafood is the most acknowledged marine ES, oceans provide much more than fishes, as mentioned above. The tight relation between primary production and marine ecosystem components and processes leads to hypothesize that marine fronts could be also ES hotspots and thus satellite chlorophyll (SATC) could be a useful marine ES indicator. There is a need for general indicators in marine systems beyond coastal areas that allow mapping ES (Townsend et al. 2018). SATC is usually limited to surface chlorophyll-*a* occasionally detecting subsurface chlorophyll-*a* maximum (Blondeau-Patissier et al. 2014), therefore underestimating chlorophyll-*a* concentration. There are, in addition, some external conditions that may introduce error in the estimations. For instance, due that chlorophyll-*a* is a photosynthetic pigment it changes with radiation conditions specially at higher latitudes where, after several months of darkness during winter, solar radiation increases sharply during spring with increasing solar elevation (Qu et al. 2006). Beside these

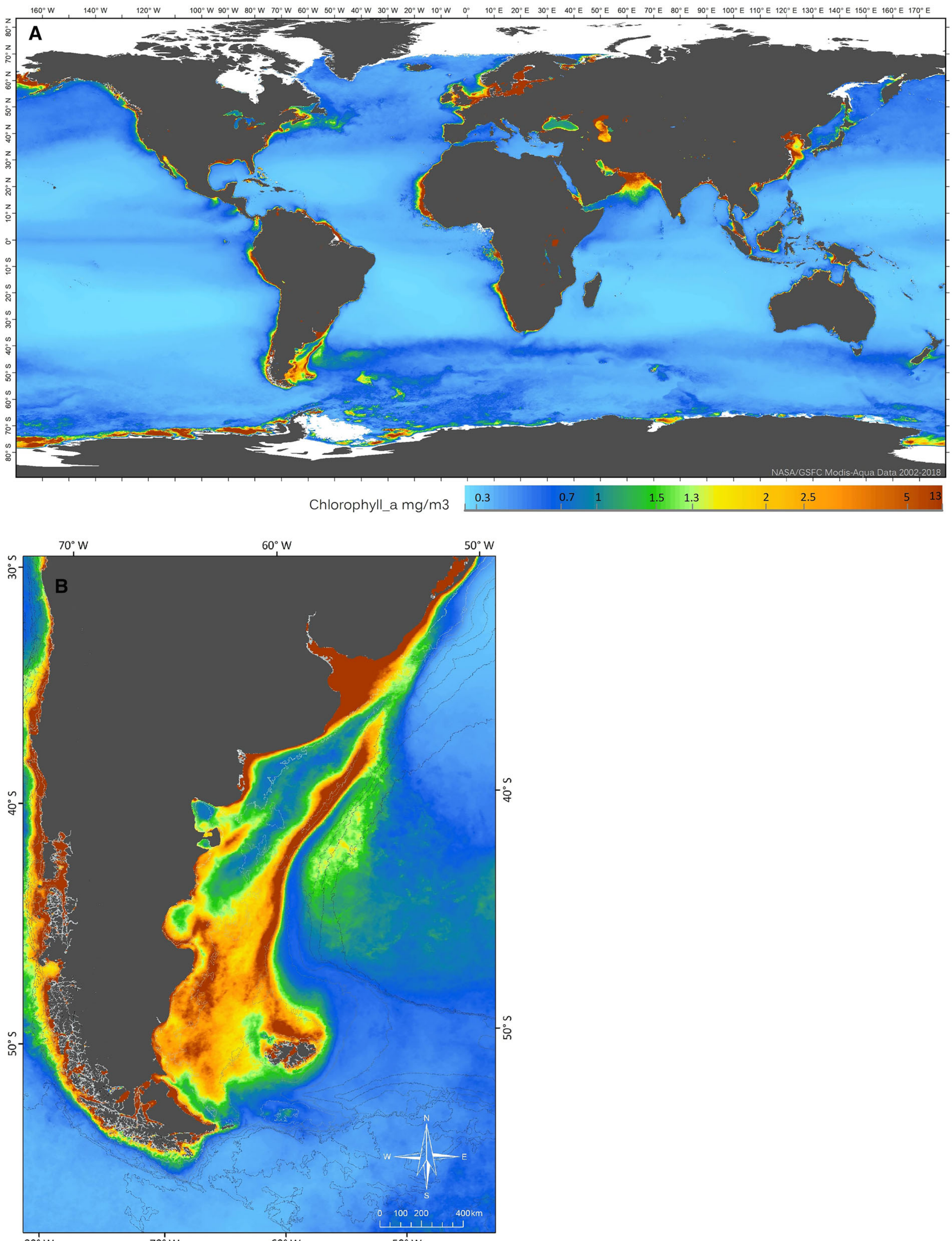

Fig. 1 Global (**a**) and Patagonian shelf large marine ecosystem (**b**) satellite chlorophyll-*a* distribution during austral summer, averaged between 2002 and 2018 (seasonal climatology). NASA Goodard Space Flight Center, Ocean Biology Processing Group; 2018: MODIS-Aqua Sensor, Ocean Color Data, NASA OB.DAAC. Greenbelt, MD, USA. Accessed 2018/10/22. Level 3 product. Resolution: 9 km

limitations, SATC is widely used as a proxy of phytoplankton biomass with large spatial and temporal coverages. Thus, marine fronts and their adjacent areas offer the opportunity to evaluate the link between primary production and marine ES production, as well as the potential of SATC as an ES indicator.

The Patagonian Shelf Large Marine Ecosystem (Sherman 2005) contains a noticeable marine frontal system situated along the Argentine shelf break. It is globally one of the most extensive chlorophyll hotspots (Fig. 1b) and is hereafter referred to as "shelf break front" (SBF). The front spans over 1500 km (approximately between 38°S and 54°S), from the confluence of the Brazil and Malvinas Currents in the north, all along the extension of the shelf break, east of the Malvinas Islands to the Burwood Bank in the south (Acha et al. 2004). Given its latitudinal extension and persistency, the SBF represents a paramount component of the SW Atlantic Ocean providing the critical resources for a large number of species (e.g. Mauna et al. 2011; Blanco et al. 2015). Altogether, these features make the SBF an excellent site to investigate the possible coupling between primary production hotspots and marine ES. In this context, we analyze the connection between marine fronts and marine ES production using the SBF as a study case. Given that the SBF is predictable and detectable by SACT (Romero et al. 2006), the analysis carried out in this study would provide further evidence of SACT as a general marine ES indicator. With this purpose, we carried out a workshop of experts from different disciplines including oceanographers, marine ecologists, terrestrial ecologists with expertise in ES, sociologists, environmental lawyers, marine resource managers and nongovernmental environmental organization representatives to revise the existing information (from scientific literature and technical reports to general public and press releases) on the SBF to integrate it under the ES framework. Under the hypothesis that primary production is linked to most of the marine ES, we collaboratively constructed the ES cascade for the SBF socio-ecosystem (Fig. 2). During the construction process, we identified the main structural components and functions of the SBF and evaluated the potential connection between intermediate services, final services, benefits, social actors and drivers of change and the chlorophyll hotspot in the SBF. Below we present evidence connecting primary production in the SBF with marine ES and introduce as a perspective the potential use of SATC as a marine ES indicator.

THE SHELF BREAK FRONT: A PRIMARY PRODUCTION HOTSPOT IN THE MARINE ENVIRONMENT

Quasi-stationary marine fronts are ubiquitous in the World Ocean (e.g. Belkin et al. 2009). Most of the stable marine fronts are guided by the bottom topography; thus, the shelf breaks and upper continental slopes play a fundamental role in the stability of their associated marine fronts (e.g. Belkin et al. 2009). The Argentine continental shelf in the Patagonian Shelf Large Marine Ecosystem is characterized by a relative flat plateau that descends to about 160 m deep and precipitates in a gentle slope reaching depths of 4000 to 5000 m. The slope represents the offshore border of the continental shelf and thus it is referred to as "shelf break". These features of the sea floor determine the formation of the SBF, a permanent thermohaline marine front that is broader and more intense during the austral spring and summer than in the cold season (Rivas and Pisoni 2010). The SBF marks the transition between low salinity shelf waters and the colder, saltier and nutrient-rich Malvinas Current waters (Romero et al. 2006).

The flow of nutrients to the surface layer is a result of the upwelling of nutrient-rich deep waters. This nutrient injection to the illuminated upper layer is essential to sustain the growth of phytoplankton and occurs continuously in the marine frontal zones due to the existence of relatively intense vertical flows (upwelling and relaxation of upwelling, Pollard and Regier 1990; Valla and Piola 2015). Harmful algal blooms (HAB) in the Southwestern Atlantic are limited to coastal areas, never exceeding the 100 m isobath; given that, HABs have never been reported for the SBF or for nearby areas (Hoffmeyer et al. 2018). Phytoplankton biomass, estimated from SATC, shows a persistent local maximum extending along the SBF. This primary production hotspot is associated with high nutrients input from the Malvinas Current and subsequent upwelling along the SBF (Valla and Piola 2015; Carreto et al. 2016). The onset of the high SATC is observed in the early austral spring and a maximum in late spring and summer (Romero et al. 2006). This conjunction of features makes the SBF the highest primary production area of the Argentine Sea and one of the most important in the world ocean (Fig. 1).

COUPLING AMONG THE SHELF BREAK FRONT AND ECOSYSTEM FUNCTIONS AND SERVICES

Bathymetry, thermohaline gradients, Malvinas current, nutrients, vertical flows and biodiversity are the main structures and processes of the SBF system (Fig. 2). These components together with the functions (primary production, energy transfer, carbon sequestration, nutrient cycling) constitute the support of ES and all the way up to the wellbeing of the beneficiaries. Below we examine the evidence that links the production of marine ES in the SBF system with primary production. In particular, we will discuss the evidences found on regulation (climate

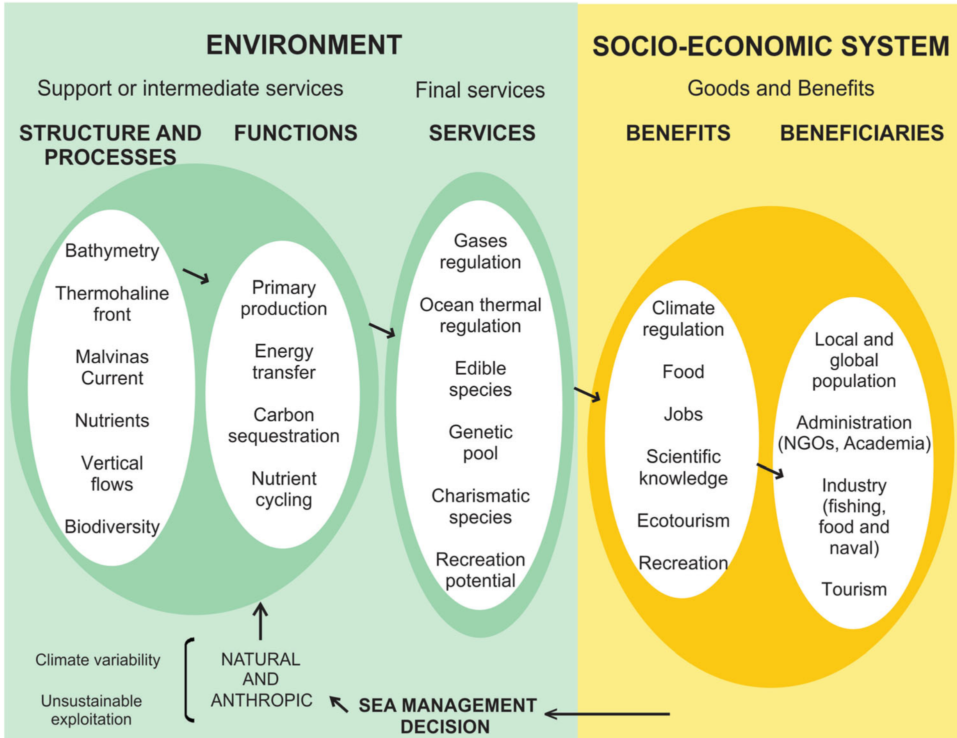

Fig. 2 Ecosystem service production functions cascade for the socio-ecological system of the shelf break front (SBF) of the Patagonian shelf large marine ecosystem

regulation), provision (seafood) and cultural (recreation and scientific potentials) services.

Climate regulation: an inconspicuous though global service

Due to primary production, the ocean captures carbon dioxide (CO_2) and is therefore one of the main regulators of the greenhouse effect (Stocker 2015). While the SBF covers only 11% of the Argentine Sea it absorbs $\sim$ 45% of the total atmospheric CO_2 captured (A. Bianchi, pers. obs.), representing the area of maximum CO_2 uptake at the Patagonian Shelf Large Marine Ecosystem. The biological pump (CO_2 uptake by phytoplankton photosynthesis) is the dominant process of the annual CO_2 balance in the Patagonian Shelf Large Marine Ecosystem, and at the SBF (Kahl et al. 2017). Thus, the production of this regulation service shows a clear dependency with primary production. This function, along with the thermal regulation of the atmosphere by the ocean, contributes to global climate regulation. The entire continental shelf and shelf break are responsible for capturing approximately 17 000 000 tons of carbon per year (Bianchi et al. 2009), which is equivalent to the total carbon emissions used by residential energy in Argentina (Bianchi et al. 2010). With the exception of some smaller-scale marine fronts, the CO_2 captured per unit area at the SBF is higher than the mean over the whole shelf region. Moreover, the shelf break has been considered as a key area for anthropogenic carbon intrusion to the ocean interior in the SW Atlantic Ocean (Orselli et al. 2018).

Ocean currents, together with the atmospheric circulation, redistribute large amounts of heat received from the sun. Thus, given its capacity to store and transport heat, the ocean plays a key role in regulating the Earth's climate. In fact, it has been suggested that the incorporation of marine fronts in climatic models could improve predictions of its future evolution (Ferrari 2011). Given the difference in temperature between continental shelf waters and waters from the Malvinas Current (e.g. Acha et al. 2004), heat transfer occurs between water masses at the SBF. Under a warming scenario, this transfer could become relevant and affect the atmosphere–ocean heat exchange. Therefore, and in addition to its capacity to uptake atmospheric CO_2, the role of the SBF in regional and global climate regulation could be important.

Fisheries: the tangible service

Several large-scale studies show that some fisheries are linked to marine frontal systems and to primary production. For instance, pelagic resources, especially large ones (e.g. Atlantic bluefin tuna *Thunnus thynnus*: Druon 2010; swordfish *Xiphias gladius*: Podestá et al. 1993) are associated with marine fronts and hence their fisheries concentrate around frontal regions. The area encompassing the Patagonian Shelf Large Marine Ecosystem and the adjacent open ocean is recognized as an important fishery ground (FAO Major Fishing Area 41). The distribution of some target species presents a strong association with the SBF. For instance, the Argentine shortfin squid (*Illex argentinus*) uses the SBF during part of its life cycle for feeding and reproduction, and therefore, the fishing effort of squid jigging vessels is concentrated in these areas (e.g. Alemany et al. 2014, Fig. 3). Moreover, the commercial exploitation of the Patagonian scallop (*Zygochlamys patagonica*) matches with the SBF where large concentrations of these organisms occur (Bogazzi et al. 2005). The Patagonian toothfish (*Dissostichus eleginoides*) is a valuable fish also caught at the SBF (Martínez and Wöhler 2016). Similarly, international fleets exploit the Argentine hake (*Merluccius hubbsi*) in a portion of the SBF located at international waters (e.g. Spanish fleets, Vilela et al. 2018).

Argentina is a country with relatively low fish consumption (4.8 kg per capita per year) within Latin America and the Caribbean (regional average of 10 kg per capita per year; FAO 2016). In fact, about 85% of the products derived from the marine fishing industry are exported (Secretaría de Agroindustria, Argentina 2018). In terms of income, fishery exports are ca. 1500 million US dollars per year, which represents around 3% of the country total exports (INDEC 2018). More than 60% of the marine primary products exported originate from only a few species: red shrimp (*Pleoticus muelleri*), Argentine hake, Argentine shortfin squid, Patagonian scallop, Patagonian hoki (*Macruronus magellanicus*) and Patagonian toothfish. Except for the red shrimp and the Argentine hake, the other four species are mainly fished at the SBF (Alemany et al. 2014). Between 2001 and 2018, the Argentine fishing sector exported on average 500 thousand tons of seafood per year, equivalent to 1300 million US dollars per year; almost 50 thousand tons, equivalent to 144 million US dollars, were at least provided by the SBF (Fig. 4). On average, the SBF contributes with 12% of the export income of seafood production.

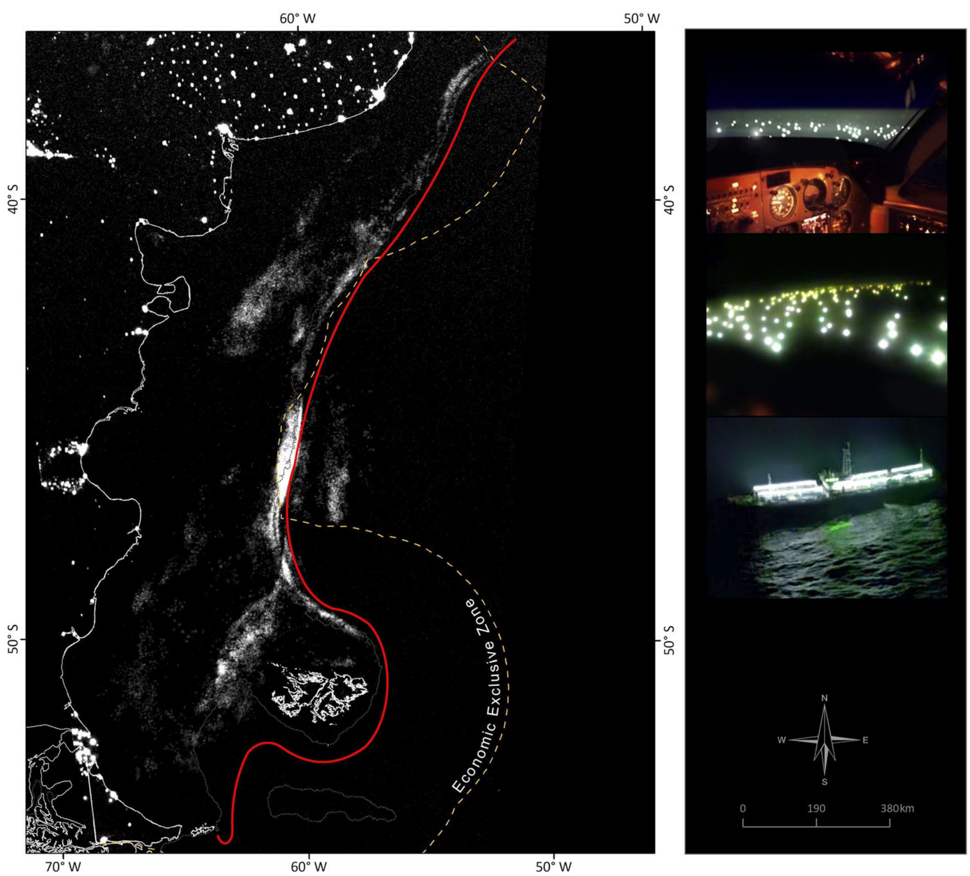

Fig. 3 Night satellite image showing the distribution of the jigging fleet fishing squids in the Argentine Sea. Low light satellite image provided by the U.S. Air Force Defense Meteorological Satellite Program and processed by the NOAA, National Geophysical Data Center; courtesy C. Elvidge. The red line indicates the average central position of the shelf break front (adapted from Acha et al. 2004). The right hand panels show photographs of the fleet (top and middle) and a single vessel (bottom) taken from a fishery surveillance airplane

A relatively small portion of the Patagonian Shelf Large Marine Ecosystem, and part of the SBF, extends beyond the Argentinean Exclusive Economic Zone. Several trans-zonal stocks that use the SBF are highly migratory, such as the Argentine shortfin squid that is also being caught around the Malvinas Islands; and in the high seas beyond Argentina's jurisdiction (Vilela et al. 2018). Thus, considering the total catches of Argentine shortfin squid in the area (including the Argentine Exclusive Economic Zone and the adjacent international waters) the SBF contributed between 1993 and 2018 with around 50% of the fishery, which on average accounts to 220 thousand tons per year equivalent to 270 million US dollars (Fig. 5). Moreover, one of the main benefits of seafood to human consumption is its high nutritional value, for example, squids consist of ~ 14% proteins (Eder and Lewis 2005). Therefore, a straightforward calculation between the average annual catch and the percentage of protein indicates that the SBF, including Argentine and international waters, provides 30 000 tons per year of proteins from squid only. Applying the same criterion, the exports of extracted proteins corresponding only to the Argentine Exclusive Economic Zone originated from the SBF amounts to 3700 tons per year (2700 tons from squids and 1000 tons from scallops adductor muscle; 15% protein for scallops, Campodónico and Garaffo 2014). This corresponds to twice the Argentina's annual beef exports. There are also important fisheries in areas adjacent to the SBF that in some cases can be indirectly supported by primary production derived from the SBF. For example, the Argentine hake, whose exports in terms of total biomass are higher than those of scallops, is captured by the Argentine fleet in the Patagonian Shelf Large Marine Ecosystem in areas close to the SBF, where the trophic web is presumably supported by the primary production in the front (Alemany et al. 2014). Thus, the SBF is an important area for fisheries not only generating economic benefits but also high-quality food supply for humans.

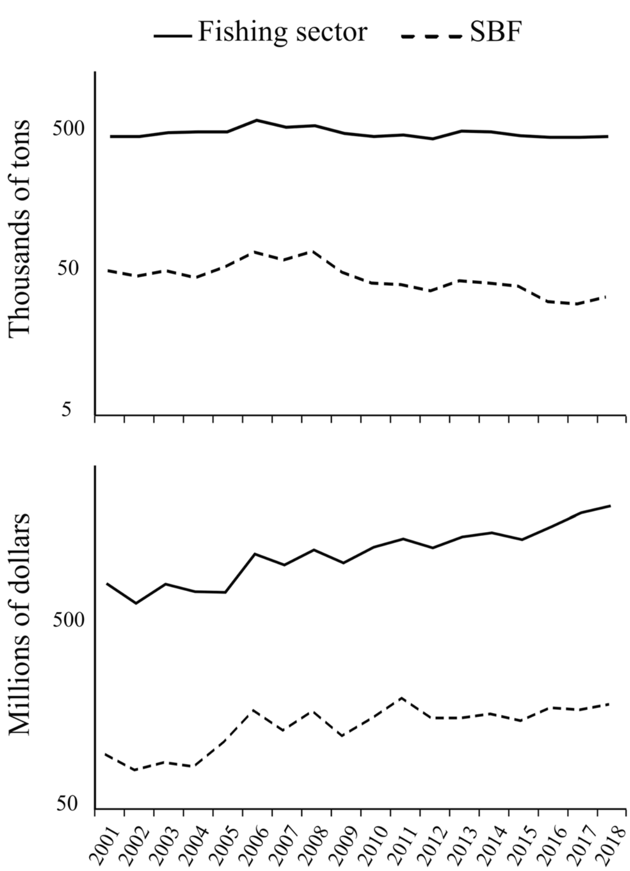

Fig. 4 Export of fishery products (in thousands of tons, upper panel) and the economic value (in millions of dollars, lower panel) of the Argentine fishing sector with the particular contribution of the SBF from 2001 to 2018. *y* axis is in log scale. See Electronic Supplementary Information for details on the calculations

Inspiration, recreation and science: the intangible services

There are also additional non-material benefits such as recreation, aesthetical enjoy and art-inspiration denominated cultural services (MEA 2005). The development of knowledge through science is also within the cultural services. The scientific research of the oceans revealed the existence and the relative importance of the SBF. Today, several research studies, including this one, are under the hypothesis that the SBF is the main primary production hotspot or the "backbone" of primary production in the Argentine Sea and that energy is exported from the SBF to the other regions in the continental shelf.

The ocean has been the original inspiration of numerous myths, legends and stories of literature, cinema and visual arts (Duarte 2010). In this sense, the space for reflection and for the cognitive development provided by nature is also included within the cultural ES; so is cultural identity, which refers to the sense of home that an individual or a social group develops with their natural surroundings. In the marine realm, far from the coasts, these cultural services are provided by the ocean as a whole and not by a particular region. Therefore, cultural services provided by the ocean are perceived different from those provided by terrestrial and coastal areas where humans usually settle and have a direct use and perception of the local environment.

Top predators such as petrels, albatross, penguins, turtles, whales, elephant seals and sea lions are some of the species considered as charismatic (i.e. megafauna, often vertebrates with a symbolic value and a widespread popular appeal) and highly valued by humans for their beauty (aesthetic value) or just their existence (intrinsic value). Some of these species, like albatross and petrels (Quintana and Dell'Arciprete

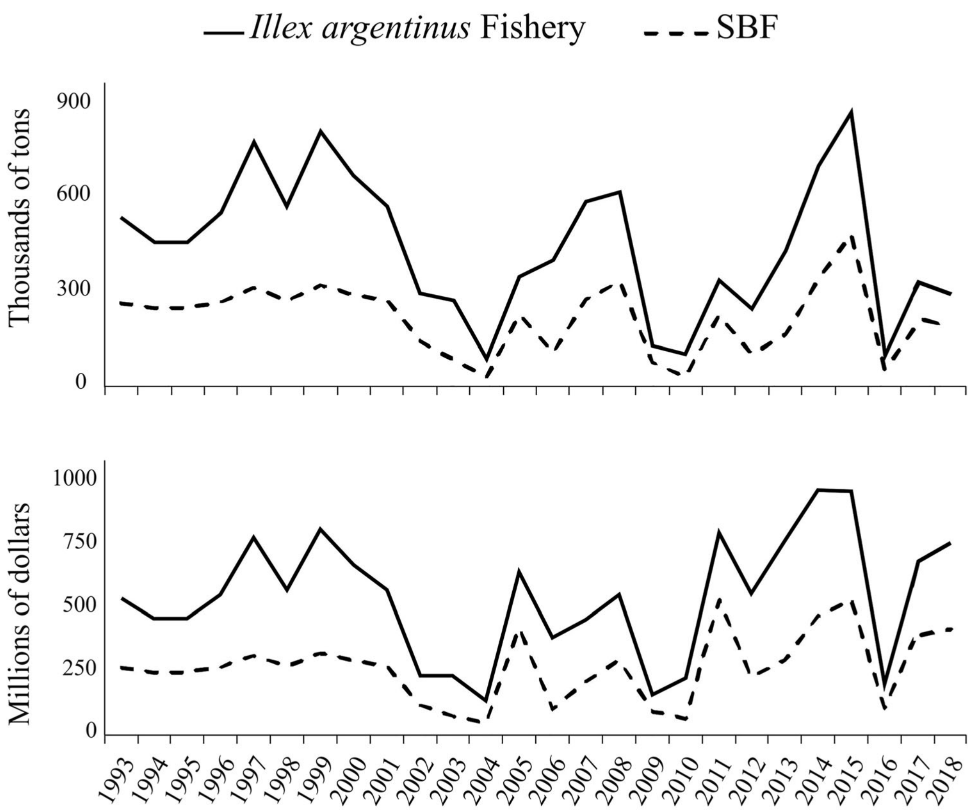

Fig. 5 Total catches of Argentine shortfin squid (in thousands of tons, upper panel) and the economic value (in millions of dollars, lower panel) with the contribution of the SBF to the fishery from 1993 to 2018. See Electronic Supplementary Information for details on the calculations

2002) and the right whales (Zerbini et al. 2016), use the SBF seasonally associated with migratory and reproductive behaviors; while others, like elephant seals, use it throughout the year (Falabella et al. 2009; Fig. 6). For instance, a large part of the elephant seal population breeding at Peninsula Valdés, travels more than 400 km from coastal areas to feed on fish and squids along the shelf break and the adjacent deep ocean, in occasions up to depths of 1000 m (Campagna et al. 2007). They maintain their reproductive areas on the coasts of Península Valdés (Argentine Patagonia, 42°S), where they are one of the main ecotourism attractions. Therefore, in this case, the benefit obtained from the ecosystem is captured hundreds of kilometers away from where it is produced. In this sense, marine ecosystems are often different from terrestrial ecosystems. On land benefits tend to be captured locally, such as economic benefits for local inhabitants, jobs, and climate regulation at local scale, although some benefits are captured on global scale (e.g. climate regulation) or far from the area of production (e.g. food and raw material export).

Biodiversity in the front

Marine fronts have been highlighted for their high consumer abundances. However, only a few studies specifically address the relationship between marine fronts and biodiversity, and the derived conclusions are somewhat contradictory (see Acha et al. 2015). However, several studies relate biodiversity patterns to the occurrence of marine fronts. For example, in the planning process for a marine-protected area, UK shelf-sea fronts were assumed as a surrogate measure for mapping the abundance and diversity of pelagic organisms (Miller and Christodoulou 2014). Though the relationship between marine biodiversity and the SBF is still being explored, some studies indicate that the SBF is a high-biodiversity area. For instance, cartilaginous fish (Lucifora et al. 2012) as well as benthic communities (Mauna et al. 2011) are more diverse in the SBF than in adjacent areas. In addition, all species make up the ecosystem genetic pool, and its biodiversity increases the chances to adapt to environmental changes. Thus, the genetic pool represents an important option value (with future potential) whose ecosystem functions and services may be important under certain environmental scenarios or if the advance of the scientific knowledge allows its role to be revealed. Moreover, the ocean represents a virtually untapped resource for the discovery of novel chemicals with pharmaceutical and cosmetic potential (Jaspars et al. 2016). New marine natural products are being continuously discovered, providing elements for the

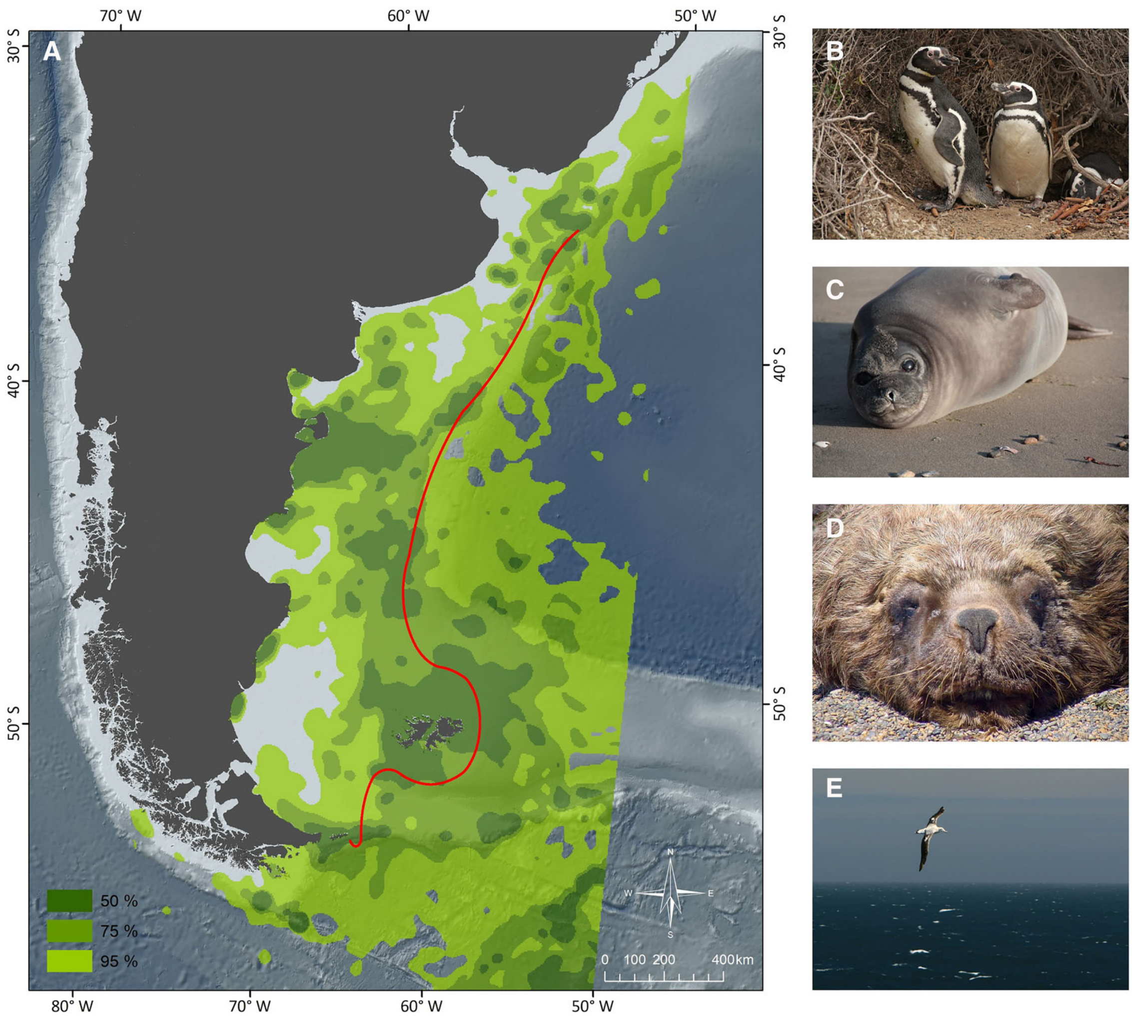

Fig. 6 **a** Distribution and habitat use areas of 16 charismatic species including albatross (5), petrels (3), penguins (4), sea lions (3) and the elephant seal (adapted from Falabella et al. 2009). The red line indicates the average central position of the shelf break front (adapted from Acha et al. 2004). Photo credits: **b**, **c**, **e** Valeria Falabella, **d** Claudio Campagna

development of new drugs (Costa Leal et al. 2012). Marine algae, plants, animals, and microbes produce compounds that have potential for treating human diseases. These "secondary metabolites" (i.e. chemicals that are not needed by the organism for basic or primary metabolic processes) are believed to confer some evolutionary advantage. The main advantage proposed for the success of marine based drug is not just the high marine chemical diversity but also the fact that marine organisms have some primitive human genetic characteristics that could be useful to unlock human medical issues (Calado et al. 2018).

Following the high primary production in the SBF, many studies have also shown an increase in the abundance or in the habitat use of several consumers such as marine birds, mammals (e.g. Bost et al. 2009) and zooplankton (e.g. Marrari et al. 2004), and of important commercial species such as Argentine shortfin squid (e.g. Chen et al. 2007), Argentine hake (e.g. Ruiz and Fondacaro 1997), Argentine anchovy (*Engraulis anchoita*, e.g. Sánchez and Ciechomski 1995) and Patagonian scallop (e.g. Soria et al. 2016). Thus, part of the high primary production in marine frontal areas is transferred as energy through the food web. This energy allows high concentration of zooplankton, mainly small crustaceans and larval stages of other organisms, which are the link between phytoplankton and small fishes like anchovy, myctophids and juveniles of other fish species or squids (e.g. Ciancio et al. 2008). Moreover, the energy transferred to top consumers such as large fishes, invertebrates, birds and marine mammals is redistributed through migratory movements to other areas of the ocean (van Deurs et al. 2016). Given the high primary and secondary production found at the SBF, and the better conditions for reproduction and feeding, this marine frontal system is ecologically relevant for a high number of species of different trophic levels, which also spans to remote regions.

FOSTERING MARINE CONSERVATION AND SUSTAINABLE MANAGEMENT UNDER THE ECOSYSTEM SERVICES APPROACH

To transcend the academic world, and guide to a better informed and rational strategy of sustainable use and conservation, the integral value of the ecosystems should be communicated to decision-makers as well as to the citizens, under governance frameworks that warrant a wide representation and participation of stakeholders. Therefore, it is necessary to raise awareness and inform society on the challenges that we face and the future potential risks. It is also necessary to assess and synthesize all available knowledge to objectively inform decision-makers based on solid scientific results. The valuation of nature based on its capacity to produce goods and services has served as a communication tool for multidisciplinary ecosystem management groups. It highlights that the loss of nature implies a cost that is paid by society, though in many cases the cost is not easily perceived and not equally understood by different stakeholders (de Groot et al. 2010). The monetary dimension of ES depends not only on the social demands for benefits, but also on the state of the ecosystems and biodiversity (biophysical values) and on the environmental behavior, local ecological knowledge, and the cultural and local identity of people (Jacobs et al. 2016).

ES are produced in bundles and, therefore, they can interact and jointly respond to natural (e.g. ENSO cycle, Antarctic Oscillation) and anthropogenic pressures (e.g. fisheries, species introduction, pollution, acidification—as a consequence of increasing CO_2). It is important and necessary to evaluate the biological production of ES, but this is not enough to define management strategies (Mastrangelo and Laterra 2015). The capture of most services requires some kind of human intervention (e.g. fishery requires fish populations but also ships, knowledge and technology) that should also be considered in the valuation. In 1997, Costanza et al. published the first economic global valuation of ES. This estimation was the corner stone for the economic valuation of the ecosystems. After several criticisms, in 2014, the economic valuation was updated acknowledging that many ES are public goods and, therefore, the conventional market is not the best institutional framework for management. Even so, this estimation expressed in monetary units has been very useful to highlight the magnitude of the ES (and their loss) without entering in a specific context of decision-making and also to make projections under different global scenarios (Kubiszewski et al. 2017). According to Costanza et al. (2014), the value of marine shelf ecosystems is 2222 US Dollars per hectare per year; applying this estimate to the Argentine Sea (whose area is approximately 1 000 000 km^2) the total value of this ecosystem is 222.2 billion US Dollars per year, which is equivalent to 40% of the Argentine gross domestic product and fourfold the value of Argentine exports in recent years (e.g. 2016 see INDEC 2018). The SBF covers an area of 107 000 km^2 which based on the same approach leads to an economic valuation of $\sim$ 24 billion US Dollars per year. In the light of the information summarized in this study, it is possible that a more accurate estimate will lead to a higher economic valuation to frontal areas given the comparatively high production of ESs.

The distribution of ES in the Argentine Sea is heterogeneous, with a particular concentration in the SBF through a tight association with primary production as the main support or intermediate service (Fig. 2). In addition, there is a significant connectivity among marine systems as well as between coastal marine and terrestrial ecosystems. The distribution patterns and the connectivity among adjacent systems require considering large spatial scales for sustainable management strategies. Moreover, multi-country agreements are also required given the large-scale displacements of water masses and the migrations of several species (e.g. several predators, Harrison et al. 2018) and the foreign fishing activities in the high seas. Thus, global changes, such as ocean warming and acidification, and also anthropogenic activities taking place in adjacent areas connected by ocean currents (e.g. mining, oil extraction) should be taken into account as potential forcing factors that are likely to alter the ecological functioning and structure of the SBF.

It is necessary to evaluate the different demands, usually subjected to conflicting interests, from all the stakeholders to identify ecologically possible and socially acceptable states of the socio-ecological system (Mastrangelo and Laterra 2015). The demands and possible conflicts are subject to individual, political and economic interests each having specific logics and dynamics. Therefore, institutions and organizations responsible for proposing and operating marine resource management strategies (public administration, nongovernmental organizations, academia) must integrate knowledge about the respective socio-ecological system. Otherwise, decisions may lead to unsatisfactory results with negative consequences for biodiversity and for the ecological functioning.

Regulation of atmospheric gases, particularly CO_2, and the provision of seafood are the most documented services; it is in part due to the increasing worldwide demand of these services and, therefore, more information is available. Provision of seafood represents an important income source for Argentina and involves different stakeholders. Therefore, the area of fishery resources is a subject of cross-cutting interest for various stakeholders (e.g. fishermen, entrepreneurs, environmentalists, governmental natural resource managers and scientists). These stakeholders may have potentially conflicting interests ranging from exploitation to sustainability and conservation that frequently lead to social and political conflicts. It is expected that knowledge of the response of target species to natural and anthropic drivers of change, together with social demand, will help partially solve some of these conflicts.

Though society may perceive the marine frontal systems as distant and unknown, the latter provide continuous benefits through the provision of multiple services. Our study shows that through high primary production, the SBF concentrates a significant provision of ESs of the Argentine Sea. Thus, the SBF should be considered a key area in the provision of ESs for an integrated management of the Argentine Sea. In addition, management should consider that ongoing or planned activities should not directly or indirectly affect the primary production in a significant way.

Finally, our study also shows that, under the ES approach, the management of this ecosystem depends on the use of integrated information on the socio-ecological system and the participation of the different stakeholders involved in developing public policies and decision-making. Therefore, we highlight the need to carry out integrated studies that allow comparison of the provision of ES in the SBF with that over the shelf and other smaller-scale marine fronts. This approach will help to lay out management strategies based on ocean heterogeneity and the provision of multiple ES.

SATELLITE CHLOROPHYLL AND MARINE FRONTS AS INDICATORS FOR MARINE ECOSYSTEM SERVICES

Moving from theory to practice, marine ES requires validated indicators (Townsend et al. 2018). The information reviewed here shows that SATC has the potential of being an excellent indicator for marine ES with the advantage that it allows for mapping at large temporal and spatial scales. Another advantage is that given the connection of primary production with most of the ES identified for marine systems, SATC can be used as a general indicator of multiple ES with further implications. Indicators should simplify the information in a way that it could be easily communicated and understood. They should help managers to take decisions based on actual evidence as well as to identify and prioritize interventions, monitor the progress of ongoing programs and opportunely make modifications. In particular, ES indicators should allow decision-makers to know and understand the state, trends and rates of change of ES.

Terrestrial systems have an analogous well-validated indicator of multiple ES: the Normalized Difference Vegetation Index (NDVI, Paruelo et al. 2016). The NDVI index, though technically differ from SATC, relies on remotely sensed primary production as SATC is. This index has been validated as a good indicator for several ES such as carbon sequestration (regulation service), biodiversity (bird richness and abundance; cultural service) and water provision (provision service). Again, pioneer terrestrial studies may serve as a cornerstone for developing methodologies for marine systems. Satellite images provide a unique large-scale approach that allows scientists to better understand the ecological ocean dynamics and identify general distributional patterns, and even to validate models (Field et al. 1998; Lutz et al. 2010). In addition to the large spatial and temporal scales that allows the identification of trends, satellite images are easily accessible at a relatively low cost, and can be combined with other variables to achieve better estimates (for instance chlorophyll in situ data help to estimate chlorophyll 3D distribution and primary production, e.g. Lutz et al. 2010). Moreover, satellite images are being increasingly used in management at different levels. Climate forecasting is one of the most widely used applications, but uses can be highly diverse. For instance, satellite images have been used to detect red tides (NOAA Harmful Algae Bloom Forecast), to monitor ocean acidification and coral bleaching (Heron et al. 2016), sea state (waves; Ardhuin et al. 2019) and to localize emperor penguin colonies (Fretwell et el. 2012). Furthermore, regimes of chlorophyll-*a* variation have been identified with SATC and used as surrogates for assemblages of species with conservation interest in marine-protected areas in the Coral Sea (Welch et al. 2015).

The validation of SATC as an indicator of marine ES requires the compilation of actual data on ES production coupled to SATC data covering temporal (e.g. seasonal and interannual time scales) and spatial (latitudinal) trends. In an initial state of analysis, SATC data will help to select the sites that deserve more observational efforts. It is also important to identify those cases in which the indicator may fail. We should also consider a misalignment between the indicator and the production of a given ES. For instance, a bloom of phytoplankton may be identified through SATC but the response in terms of fish biomass may be found several months or even years later. In this sense, it is crucial to analyze time series.

Within the ES approach, social sciences and mapping (with information on the spatial distribution of ecological components) are clearly underrepresented (Liquete et al. 2013) due to the above-mentioned limitations. As shown in preceding sections, the association between high primary production and ocean fronts, fisheries, CO_2 sequestration and biodiversity are well documented. Given the link between several ES such as seafood, climate regulation and biodiversity to marine fronts (through the high primary production present there), we propose that SATC may be a good indicator to identify hot spots of marine ES. This proposed indicator can be remotely monitored, providing information at large spatial and temporal scales, and serving for multiple ES.

CONCLUSIONS

The reviewed information indicates that high primary production (identified through SATC) associated with the SBF is the main ecological feature that supports the production of marine ES, and the reason why the provision of ES in the Argentine Sea concentrates there. This information provides additional support to our initial proposal of SATC as a useful indicator of multiple ES at large temporal and spatial scales. We synthesized how the high primary production present in marine frontal systems subsidizes the production of ES, and therefore, these areas could be considered as marine ES hotspots.

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REFERENCES

Acha, E.M., H.W. Mianzan, R.A. Guerrero, M. Favero, and J. Bava. 2004. Marine fronts at the continental shelves of austral South America: Physical and ecological processes. *Journal of Marine System* 44: 83–105.

Acha, E.M., A. Piola, O. Iribarne, and H. Mianzan. 2015. *Ecological processes at marine fronts, oases in the ocean*. Mar del Plata: Springer.

Alemany, D., E.M. Acha, and O. Iribarne. 2014. Marine fronts are important fishing areas for demersal species at the Argentine Sea (Southwest Atlantic Ocean). *Journal of Sea Research* 87: 56–67.

Ardhuin, F., J.E. Stopa, B. Chapron, F. Collard, R. Husson, R.E. Jensen, J. Johannessen, A. Mouche, et al. 2019. Observing sea states. *Frontiers in Marine Science* 6: 124. https://doi.org/10.3389/fmars.2019.00124.

Armstrong, C.W., N.S. Foley, R. Tinch, and S. van den Hove. 2012. Services from the deep: Steps towards valuation of deep sea goods and services. *Ecosystem Services* 2: 2–13.

Barbier, E.B., S.D. Hacker, C. Kennedy, E.W. Koch, A.C. Stier, and B.R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81: 169–193.

Belkin, I.M., P.C. Cornillon, and K. Sherman. 2009. Fronts in large marine ecosystems. *Progress in Oceanography* 81: 223–236.

Benoit-Bid, K.J., and M.A. NcManus. 2012. Bottom-up regulation of a pelagic community through spatial aggregations. *Biological Letters* 8: 813–816.

Bergstad, O.A., E. Johannesen, Å. Høines, K.E. Ellingsen, V.S. Lien, I. Byrkjedal, N.G. Yoccoz, T. Tveraa, et al. 2018. Demersal fish assemblages in the boreo-Arctic shelf waters around Svalbard during the warm period 2007–2014. *Polar Biology* 41: 125–142.

Bianchi, A.A., A.P. Osiroff, C.F. Balestrini, A.R. Piola, and H.I. Perlender. 2010. Atrapando CO_2 en el mar patagónico. *Ciencia Hoy* 20: 8–23.

Bianchi, A.A., D.R. Pino, H.G.I. Perlender, A.P. Osiroff, V. Segura, V. Lutz, M.L. Clara, C.F. Balestrini, et al. 2009. Annual balance and seasonal variability of sea-air CO_2 fluxes in the Patagonia Sea: Their relationship with fronts and chlorophyll distribution. *Journal of Geophysical Research: Oceans* 114: C03018.

Blanco, G.S., J.P. Pisoni, and F. Quintana. 2015. Characterization of the seascape used by juvenile and wintering adult Southern Giant Petrels from Patagonia Argentina. *Estuarine, Coastal and Shelf Science* 153: 135–144.

Blondeau-Patissier, D., J.F.R. Gower, A.G. Dekker, S.R. Phinn, and V.E. Brando. 2014. A review of ocean color remote sensing methods and statistical techniques for the detection, mapping and analysis of phytoplankton blooms in coastal and open oceans. *Progress in Oceanography* 123: 123–144.

Bogazzi, E., A. Baldoni, A. Rivas, P. Martos, R. Reta, J.M. Orensanz, M. Lasta, P. Dell'Arciprete, et al. 2005. Spatial correspondence between areas of concentration of Patagonian scallop (*Zygochlamys patagonica*) and frontal systems in the southwestern Atlantic. *Fisheries Oceanography* 14: 359–376.

Bost, C.A., C. Cotté, F. Bailleul, Y. Cherel, J.B. Charrassin, C. Guinet, D.G. Ainley, and H. Weimerskirch. 2009. The importance of oceanographic fronts to marine birds and mammals of the southern oceans. *Journal of Marine Systems* 78: 363–376.

Cáceres, D.M., E. Tapella, F. Quétier, and S. Díaz. 2015. The social value of biodiversity and ecosystem services from the perspectives of different social actors. *Ecology and Society* 20: 62.

Calado, R., M. Costa Leal, H. Gaspar, S. Santos, A. Marques, M.L. Nunes, and H. Vieira. 2018. How to succeed in marketing marine natural products for nutraceutical, pharmaceutical and cosmeceutical markets. In *Grand challenges in marine biotechnology, grand challenges in biology and biotechnology*, ed. P.H. Rampelotto and A. Trincone, 317–404. New York: Springer.

Campagna, C., A.R. Piola, M.R. Marin, M. Lewis, U. Zajaczkovski, and T. Fernández. 2007. Deep divers in shallow seas: Southern elephant seals on the Patagonian shelf. *Deep-Sea Research* 54: 1792–1814.

Campodónico, S., and G.V. Garaffo. 2014. Variación estacional de los índices gonadal y muscular de *Zygochlamys patagónica* (King, 1832) en relación con el almacenamiento de reservas energéticas. *Revista de Investigación y Desarrollo Pesquero (INIDEP)* 24: 75.

Carreto, J.I., N.G. Montoya, M.O. Carignan, R. Akselman, E.M. Acha, and C. Derisio. 2016. Environmental and biological factors controlling the spring phytoplankton bloom at the Patagonian shelf-break front—Degraded fucoxanthin pigments and the importance of microzooplankton grazing. *Progress in Oceanography* 146: 1–21.

Chassot, E., S. Bonhommeau, N.K. Dulvy, F. Mélin, R. Watson, D. Gascuel, and O. Le Pape. 2010. Global marine primary production constrains fisheries catches. *Ecology Letters* 13: 495–505.

Chen, C.S., T.S. Chiu, and W.B. Haung. 2007. The spatial and temporal distribution patterns of the Argentine short-finned squid, *Illex argentinus*, abundances in the Southwest Atlantic and the effects of environmental influences. *Zoological Studies* 46: 111–122.

Ciancio, J.E., M.A. Pascual, F. Botto, E. Frere, and O. Iribarne. 2008. Trophic relationships of exotic anadromous salmonids in the southern Patagonian Shelf as inferred from stable isotopes. *Limnology and Oceanography* 53: 788–798.

Cognetti, G., and F. Maltagliati. 2010. Ecosystem service provision: An operational way for marine biodiversity conservation and management. *Marine Pollution Bulletin* 60: 1916–1923.

Costa Leal, M., J. Puga, J. Serôdio, N.C.M. Gomes, and R. Calado. 2012. Trends in the discovery of new marine natural products from invertebrates over the last two decades—Where and what are we bioprospecting? *PLoS ONE* 7: e30580.

Costanza, R., R. de Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, et al. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253–260.

Costanza, R., R. de Groot, P. Sutton, S. van der Ploeg, S.J. Anderson, I. Kubiszewski, S. Farber, and R.K. Turner. 2014. Changes in the global value of ecosystem services. *Global Environmental Changes* 26: 152–158.

de Groot, R.S., B. Fisher, M. Christie, J. Aronson, L.C. Braat, R. Haines-Young, J. Gowdy, E. Maltby, et al. 2010. Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation, Chap. 1. In *The economics of ecosystems and biodiversity (TEEB): Ecological and economic foundations*, ed. P. Kumar, 9–40. London: TEEB Foundations.

Druon, J.N. 2010. Habitat zapping of the Atlantic blue fin tuna derived from satellite data: Its potential as a tool for the sustainable management of pelagic fisheries. *Marine Policy* 34: 293–297.

Duarte, C.M. 2010. *Océano, el secreto del planeta Tierra*. Madrid: Los libros de la Catarata, CSIC.

Duarte, C.M., R.W. Fulweiler, C.E. Lovelock, P. Martinetto, M. Saunders, J.M. Pandolfi, S. Gelcich, and S. Nixon. 2015. Reconsidering ocean calamities. *BioScience* 65: 130–139.

Eder, E.B., and M.N. Lewis. 2005. Proximate composition and energetic value of demersal and pelagic prey species from the SW Atlantic Ocean. *Marine Ecology Progress Series* 291: 43–52.

Falabella, V., C. Campagna, and J. Croxall. 2009. *Atlas of the Patagonian Sea: Species and spaces*. Buenos Aires: Wildlife Conservation Society and BirdLife International.

Falkowski, P.G., R.T. Barber, and V. Smetacek. 1998. Biogeochemical controls and feedbacks on ocean primary production. *Science* 281: 200–206.

FAO. 2016. *El estado mundial de la pesca y la acuicultura 2016*. Contribución a la seguridad alimentaria y la nutrición para todos. Rome: FAO.

Ferrari, R. 2011. A frontal challenger for climate models. *Science* 332: 316–317.

Field, C.B., M.J. Behrenfeld, J.T. Randerson, and P. Falkowski. 1998. Primary production of the biosphere: Integrating terrestrial and oceanic components. *Science* 281: 237–240.

Fisher, B., R.K. Turner, and P. Morling. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68: 643–653.

Fretwell, P.T., M.A. LaRue, P. Morin, G.L. Kooyman, B. Wienecke, N. Ratcliffe, A.J. Fox, A.H. Fleming, et al. 2012. An emperor penguin population estimate: The first global, synoptic survey of a species from space. *PLoS One* 7: e33751. https://doi.org/10.1371/journal.pone.0033751.

Harrison, A.L., D.P. Costa, A.J. Winship, S.R. Benson, S.J. Bograd, M. Antolos, A.B. Carlisle, H. Dewar, et al. 2018. The political biogeography of migratory marine predators. *Nature Ecology & Evolution* 2: 1571–1578.

Heron, S.F., L. Johnston, G. Liu, E.F. Geiger, J.A. Maynard, J.L. De La Cour, S. Johnson, R. Okano, et al. 2016. Validation of reef-scale thermal stress satellite products for coral bleaching monitoring. *Remote Sensing* 8: 59. https://doi.org/10.3390/rs8010059.

Hoffmeyer, M.S., M.E. Sabatini, F.P. Brandini, D.L. Calliari, and N.H. Santinelli. 2018. *Plankton ecology of the Southwestern Atlantic—From the subtropical to the subantarctic realm. Part VI: Harmful algae and their impacts*, 453–515. New York: Springer.

INDEC. 2018. Instituto Nacional de Estadísticas y Censo, Argentina. https://www.indec.gob.ar/. Accessed 26 Nov 2018.

Jaspars, M., D. de Pascalle, J.H. Andersen, F. Reyes, A.D. Crawford, and A. Ianora. 2016. The marine biodiscovery pipeline and ocean medicines of tomorrow. *Journal of the Marine Biological Association of the United Kingdom* 96: 151–158.

Jacobs, S., N. Dendoncker, B. Martín-López, D.N. Barton, E. Gomez-Baggethun, F. Boeraeve, F.L. McGrath, K. Vierikko, et al. 2016. A new valuation school: Integrating diverse values of nature in resource and land use decisions. *Ecosystem Services* 22: 213–220.

Kahl, L.C., A.B. Bianchi, A.P. Osiroff, D. Ruiz Pino, and A.R. Piola. 2017. Distribution of sea-air CO_2 fluxes in the Patagonian Sea: Seasonal, biological and thermal effects. *Continental Shelf Research* 143: 18–28.

Kubiszewski, I., R. Costanza, S. Anderson, and P. Sutton. 2017. The future value of ecosystem services: Global scenarios and national implementation. *Ecosystem Services* 26: 289–301.

Kummu, M., H. de Moel, G. Salvucci, D. Viviroli, P.J. Ward, and O. Varis. 2016. Over the hills and further away from coast: Global geospatial patterns of human and environment over the 20th–21st centuries. *Environmental Research Letters* 1: 034010.

Kurlansky, M. 1998. *Cod: A biography on the fish that changed the world*. New York: Penguin Random House.

Lembke, C., S. Grasty, A. Silverman, H. Broadbent, S. Butcher, and S. Murawski. 2017. The camera-based assessment survey system (C-BASS): A towed camera platform for reef fish abundance surveys and benthic habitat characterization in the Gulf of Mexico. *Continental Shelf Research* 151: 62–71.

Leitner, A.B., A.B. Neuheimer, E. Donlon, C.R. Smith, and J.C. Drazen. 2017. Environmental and bathymetric influences on abyssal bait-attending communities of the Clarion Clipperton Zone. *Deep-Sea Research Part I* 125: 65–80.

Liquete, C., C. Piroddi, E.G. Drakou, L. Gurney, S. Katsanevakis, A. Charef, and B. Egoh. 2013. Current status and future prospects for the assessment of marine and coastal ecosystem services: A systematic review. *PLoS ONE* 8: e67737.

Lucifora, L., V. García, R. Menni, and B. Worm. 2012. Spatial patterns in the diversity of sharks, rays, and chimaeras (Chondrichthyes) in the Southwest Atlantic. *Biodiversity and Conservation* 21: 407–419.

Lutz, V.A., V. Segura, A.I. Dogliotti, D. Gagliardini, A. Bianchi, and C.F. Balestrini. 2010. Primary production in the Argentine Sea during spring estimated by field and satellite models. *Journal of Plankton Research* 32: 181–195.

Mann, K.H., and J.R.N. Lazier. 2006. *Dynamics of marine ecosystems biological-physical interactions in the oceans*. Cambridge: Blackwell.

Marrari, M., M.D. Viñas, P. Martos, and D. Hernández. 2004. Spatial patterns of mesozooplankton distribution in the Southwestern Atlantic Ocean (34°-41°S) during austral spring: Relationship with the hydrographic conditions. *ICES Journal of Marine Science* 61: 667–679.

Martínez, P.A., and O.C. Wöhler. 2016. Hacia la recuperación de la pesquería de la merluza negra (*Dissostichus eleginoides*) en el Mar Argentino: un ejemplo de trabajo conjunto entre el sector de la administración, la investigación y la industria. *Frente Marítimo* 24: 115–124.

Mastrangelo, M.E., and P. Laterra. 2015. From biophysical to social-ecological trade-offs: integrating biodiversity conservation and

agricultural production in the Argentine Dry Chaco. *Ecology and Society* 20: 1.
Mauna, A.C., E.M. Acha, M.L. Lasta, and O.O. Iribarne. 2011. The influence of a large SW Atlantic shelf-break frontal system on epibenthic community composition, trophic guilds and diversity. *Journal of Sea Research* 66: 39–46.
Millennium Ecosystem Assessment (MEA). 2005. *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.
Miller, P.I., and S. Christodoulou. 2014. Frequent locations of oceanic fronts as an indicator of pelagic diversity: Application to marine protected areas and renewables. *Marine Policy* 45: 318–329.
O'dea, E.J., A.K. Arnold, K.P. Edwards, R. Furner, P. Hyder, M.J. Martin, J.R. Siddorn, D. Storkey, et al. 2012. An operational ocean forecast system incorporating NEMO and SST data assimilation for the tidally driven European North-West shelf. *Journal of Operational Oceanography* 5: 3–17.
Orselli, I.B.M., R. Kerr, R.G. Ito, V.M. Tavano, C.R.B. Mendes, and C.A.E. Garcia. 2018. How fast is the Patagonian shelf-break acidifying? *Journal of Marine Systems* 178: 1–14.
Paruelo, J.M., M. Texeira, L. Staiano, M. Mastrángelo, L. Amdan, and F. Gallego. 2016. An integrative index of ecosystem services provision based in remotely sensed data. *Ecological Indicators* 71: 145–154.
Podestá, G.P., J.A. Browder, and J.J. Hoey. 1993. Exploring the relationship between swordfish catch rates and thermal fronts on U.S. longline grounds in the western North Atlantic. *Continental Shelf Research* 13: 253–277.
Pollard, R.T., and L. Regier. 1990. Large variations in potential vorticity at small spatial scales in the upper ocean. *Nature* 348: 227.
Poloczanska, E.S., M.T. Burrows, C.J. Brown, J. García Molinos, B.S. Halpern, O. Hoegh-Guldberg, C.V. Kappel, P.J. Moore, et al. 2016. Responses of marine organisms to climate change across oceans. *Frontiers in Marine Science* 3: 62.
Qu, B., A.J. Gabric, and P.A. Matrai. 2006. The satellite-derived distribution of chlorophyll-a and its relation to ice cover, radiation and sea surface temperature in the Barents Sea. *Polar Biology* 29: 196–210.
Quintana, F., and O.P. Dell'Arciprete. 2002. Foraging grounds of southern giant petrels (*Macronectes giganteus*) on the Patagonian shelf. *Polar Biology* 25: 159–161.
Rhein, M., Rintoul, S.R., Aoki, S., Campos, E., Chambers, D., Feely, R.A., Gulev, S., Johnson, G.C., et al. 2013. *Climate change 2013: The physical science basis*. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press.
Rivas, A.L., and J.P. Pisoni. 2010. Identification, characteristics and seasonal evolution of surface thermal fronts in the Argentinean Continental Shelf. *Journal of Marine Systems* 79: 134–143.
Romero, S.I., A.R. Piola, M. Charo, and C.A.E. Garcia. 2006. Chlorophyll a variability off Patagonia based on SeaWiFS data. *Journal of Geophysical Research: Oceans* 111: C05021.
Ruiz, A.E., and R.R. Fondacaro. 1997. Diet of hake (*Merluccius hubbsi* Marini) in a spawning and nursery area within Patagonian shelf waters. *Fisheries Research* 30: 157–160.
Sagebiel, J., C. Schwartz, M. Rhozyel, S. Rajmis, and J. Hirschfeld. 2016. Economic valuation of Baltic marine ecosystem services: Blind spot and limited consistency. *ICES Journal of Marine Science* 73: 991–1003.
Sánchez, R.P., and J. Ciechomski. 1995. Spawning and nursery grounds of pelagic fish species in the sea-shelf off Argentina and adjacent areas. *Scientia Marina* 59: 455–478.
Secretaría de Agroindustria, Informe de Coyuntura. 2018. https://www.agroindustria.gob.ar/sitio/areas/pesca_maritima/informes/coyuntura/_archivos//000000_2018/181001_Informe%20de%20coyuntura%20-%20Octubre%202018.pdf. Accessed 26 Nov 2018.
Sherman, K. 2005. The large marine ecosystem approach for assessment and management of ocean coastal waters. In *Sustaining large marine ecosystems: The human dimension*, ed. T.M. Hennessey and J.G. Sutinen, 3–16. Amsterdam: Elsevier.
Soria, G., J.M. Orensanz, E.M. Morsán, A.M. Parma, and R.O. Amoroso. 2016. Chapter 25—Scallops biology, fisheries, and management in Argentina. In *Developments in aquaculture and fisheries science*, ed. S.E. Shumway and G.J. Parsons, 1019–1046. Amsterdam: Elsevier.
Stocker, T.F. 2015. The silent services of the world ocean. *Science* 350: 764–765.
Takahashi, T., S.T. Sutherland, C. Sweeney, A. Poisson, N. Metzl, B. Tilbrook, N. Bates, R. Wanninkhif, et al. 2002. Global sea-air CO_2 flux based on climatological surface ocean pCO_2, and seasonal biological and temperature effects. *Deep-Sea Research II* 49: 1601–1622.
Thurber, A.R., A.K. Sweetman, B.E. Narayanaswamy, D.O.B. Jones, J. Ingels, and R.L. Hansman. 2014. Ecosystem function and services provided by the deep sea. *Biogeosciences* 11: 3941–3963.
Townsend, M., K. Davies, N. Hanley, J.E. Hewitt, C.J. Lundquist, and A.M. Lohrer. 2018. The challenge of implementing the marine ecosystem service concept. *Frontiers in Marine Science* 5: 359.
Valla, D., and A.R. Piola. 2015. Evidence of upwelling events at the northern Patagonian shelf break. *Journal of Geophysical Research: Oceans* 120: 7635–7656.
van Deurs, M., A. Persson, M. Lindegren, C. Jacobsen, S. Neuenfeldt, C. Jørgensen, and P.A. Nilsson. 2016. Marine ecosystem connectivity mediated by migrant–resident interactions and the concomitant cross-system flux of lipids. *Ecology and Evolution* 6: 4076–4087.
Vilela, R., D. Conesa, J.L. del Rio, A. López-Quílez, J. Portela, and J.M. Bellido. 2018. Integrating fishing spatial patterns and strategies to improve high seas fisheries management. *Marine Policy* 94: 132–142.
Weatherdon, L.V., A.K. Magnan, A.D. Rogers, U.R. Sumaila, and W.W.L. Cheung. 2016. Observed and projected impacts of climate change on marine fisheries, aquaculture, coastal tourism, and human health: An update. *Frontiers in Marine Science* 3: 48.
Welch, H., R.L. Pressey, S.F. Heron, D.M. Ceccarelli, and A.J. Hobday. 2015. Regimes of chlorophyll-a in the Coral Sea: Implications for evaluating adequacy of marine protected areas. *Ecography* 39: 286–304.
Woodson, C.B., and S.Y. Litvin. 2015. Ocean fronts drive marine fishery production and biogeochemical cycling. *PNAS* 112: 1710–1715.
Zerbini, A.N., H. Rosenbaum, M. Mendez, F. Sucunza, A. Andriolo, G. Harris, P.J. Clapham, M. Sironi, et al. 2016. Tracking southern right whales through the Southwest Atlantic: An update on movements, migratory routes and feeding destinations. In *Paper SC/66b/BRG/26 presented to the International Whale Commission Scientific Committee, June 2016, Bled, Slovenia*, 16pp.

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