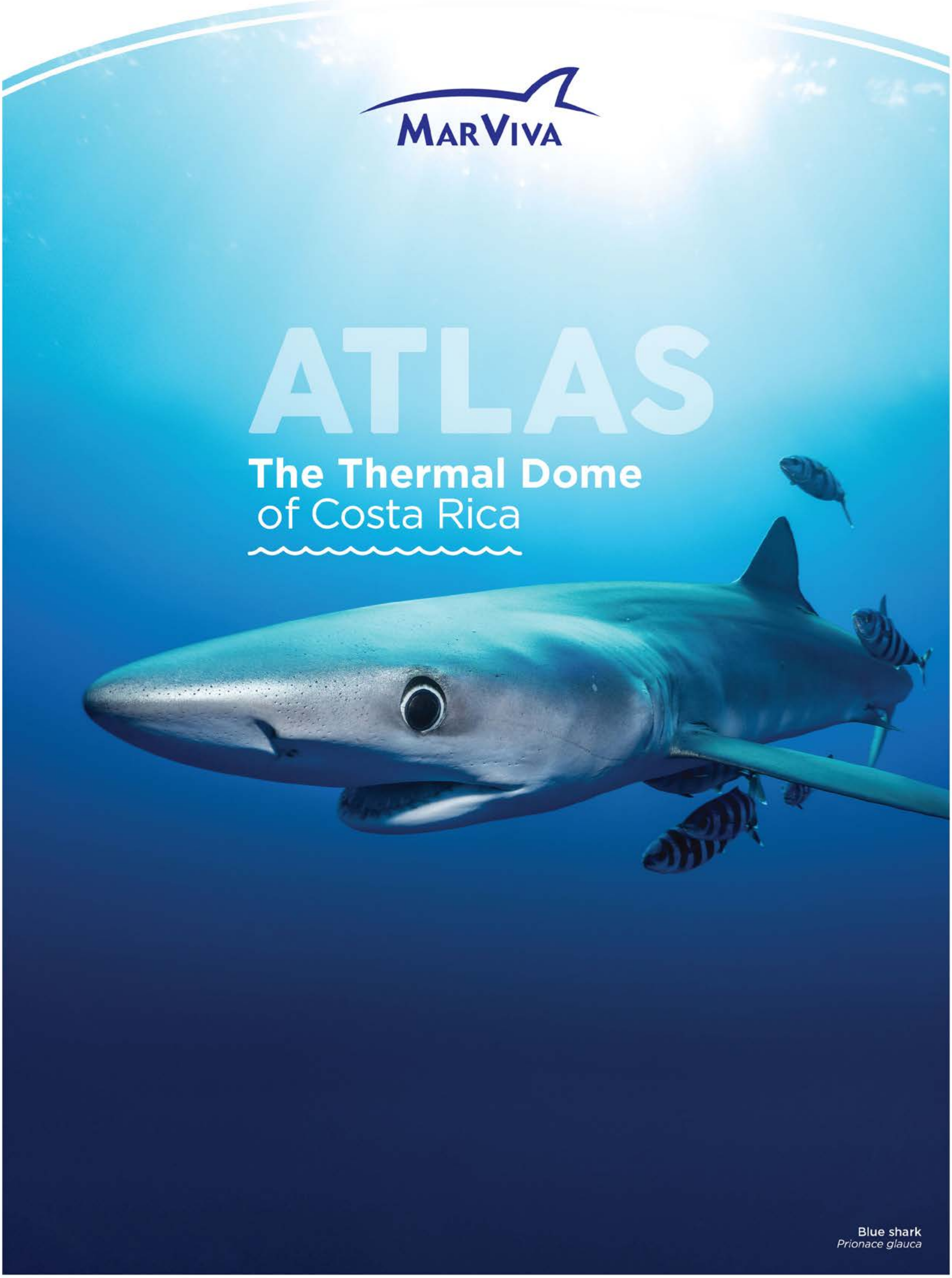
MarViva

ATLAS

The Thermal Dome of Costa Rica



Blue shark
Prionace glauca

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Spinner dolphin
Stenella longirostris

Leatherback turtle
Dermochelys coriacea

Presentation

The Dome is an oceanographic phenomenon of great relevance for Central America. The dependence that exists between many organisms of the coast and the Dome, located mostly in international waters, determines the ecology and economy of the Central American coastal zones.

In the Pacific coast of Central America, activities such as fishing, whale watching and coastal tourism in general, have a high dependence on the Dome.

Despite its importance, the Dome is mostly unknown. More critical still, its relevance to Central American countries is widely ignored. MarViva has been promoting in recent years the awareness of the public and political decision makers in the region on this issue. However, there is still a lot to do!

We are sure that the present Atlas will be another step in this important process of publicizing the Dome and its relevance. It is inevitable that once its critical function is understood, the countries of the isthmus will promote the sustainable management of this region.

Central America will benefit greatly from a sustainably managed Dome, where fishing and maritime navigation produce the least possible impact to the habitats and critical species that inhabit or frequent the Dome. Only with the joint effort of the region will this goal be achieved.

We hope that in the coming years the consolidation of a regional model of governance for the Dome, which affects international organizations, making them appreciate this oceanographic phenomenon and commit to protect the processes and resources present in the Dome region.

Dr. Jorge A. Jiménez Ramón
General Director
MarViva Foundation

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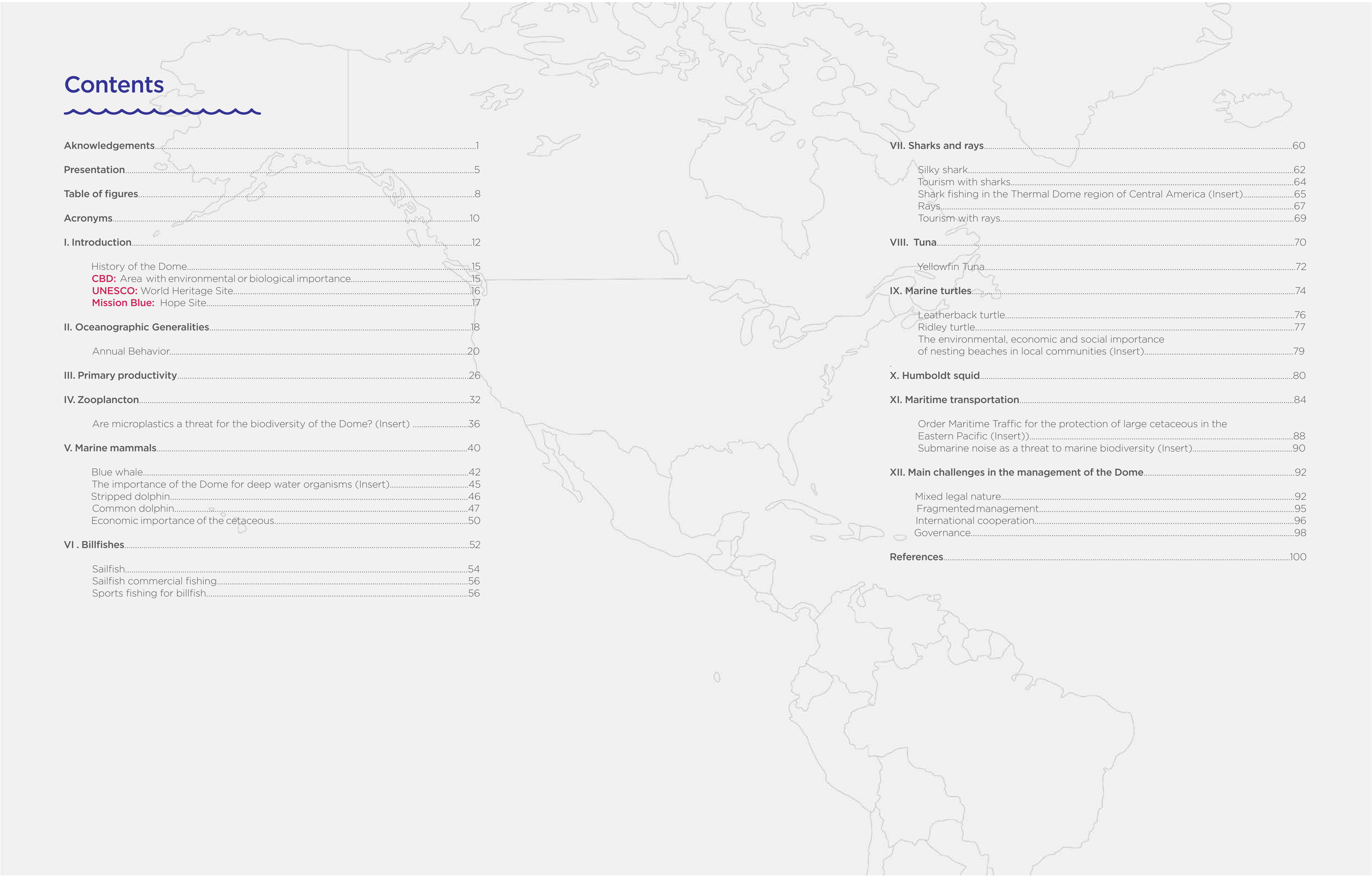

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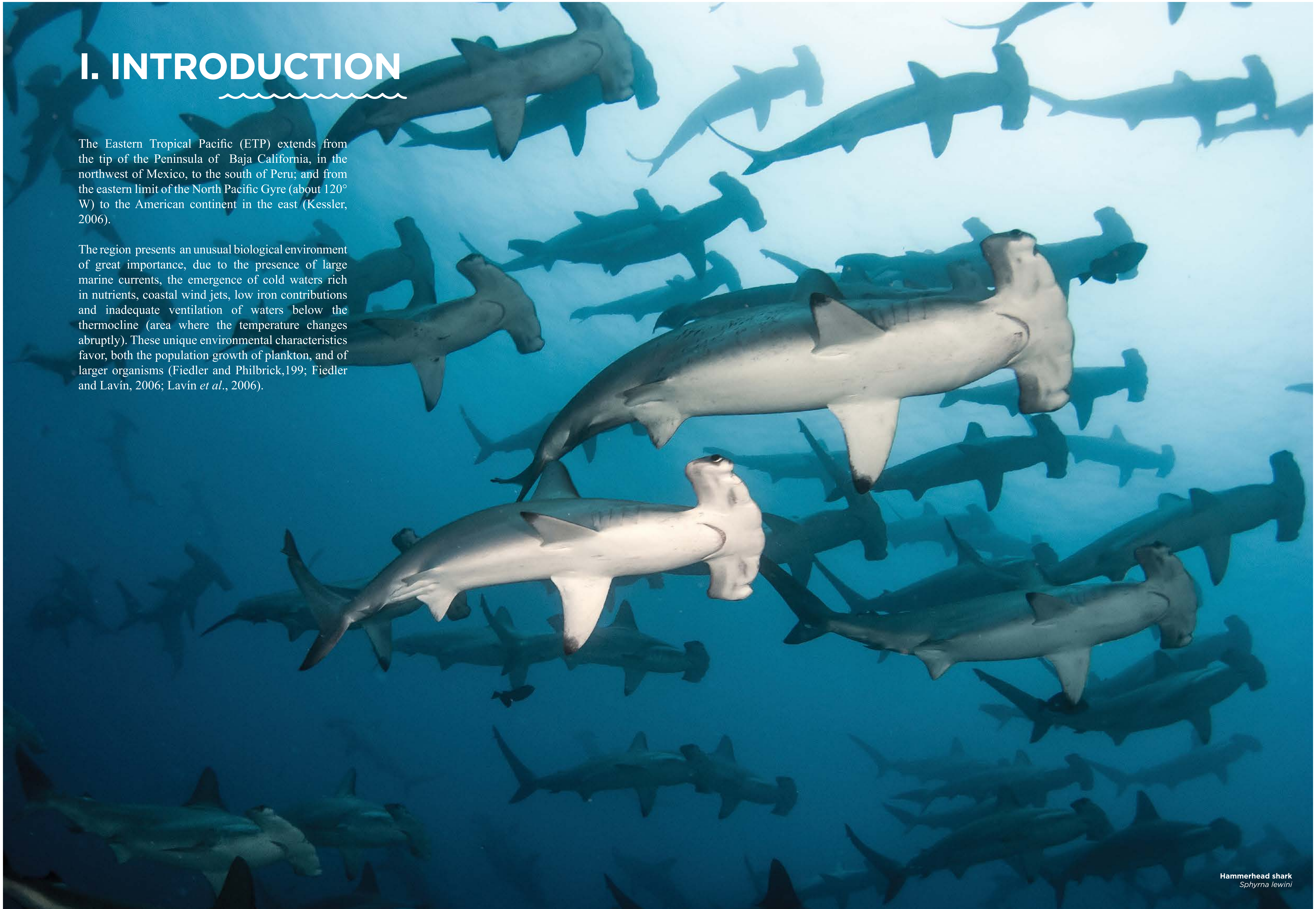
Acronyms

ABNJ	Areas Beyond National Jurisdiction.
ADIO	Asociación de Desarrollo Integral de Ostional (*Comprehensive Ostional Development Association*).
BIOMARCC	Biodiversidad Marino Costera y Adaptación al Cambio Climático (*Marine Biodiversity and Adaptation to Climate Change*).
CABA	Central American Billfish Association.
CCAD	Comisión Centroamericana de Ambiente y Desarrollo. (*Central American Commission on Environment and Development*).
CBD	Convention on Biological Diversity.
NECC	North Equatorial Counter Current.
IATTC	Interamerican Tropical Tuna Commission.
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora.
CMS	Convention on the Conservation of Migratory Species of Wild Animals.
COCATRAM	Comisión Centroamericana de Transporte Marítimo. (*Central American Comission of Maritime Transport*).
UNCLOS	United Nations Convention on the Law of the Sea.
Dome	Thermal Dome of Costa Rica.
DSV	Deep Submarine Vessel (*Deep-Submergence Vehicle*).
TSD	Transit Separation Device.
TDCR	Thermal Dome of Costa Rica.
EBSAs	Ecologically or Biological Significant Marine Areas.
FFI	Flora and Fauna International.
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection.
GiZ	German Technical Cooperation Agency (*Gesellschaft für Internationale Zusammenarbeit*).
GOBI	Global Ocean Biodiversity Initiative.
INCOPESCA	Instituto Costarricense de Pesca y Acuicultura. (*Costa Rican Institute of Fisheries and Aquaculture*).
Kg	kilograms.
km	kilometers.
km^{2}	square kilometers.
MARENA	Ministerio de Ambiente y Recursos Naturales de Nicaragua. (*Ministry of Environment and Natural Resources of Nicaragua*).
MARN	Ministerio de Medio Ambiente y Recursos Naturales de El Salvador. (*Ministry of Environment and Natural Resources of El Salvador*).
MiAMBIENTE	Ministry of Environment of Panama.
m^{3}	cubic meters.
ml	milliliters.
ml/l	milliliters per liter.
mm	millimeters.
nm	nautical miles.
GLM	Generalized Linear Model.
NOAA	National Oceanic and Atmospheric Administration.
IMO	International Maritime Organization.
NGO	Non-Governmental Organization.
UN	United Nations.
UNEP	United Nations Environment Program.
OROP	Organizaciones Regionales de Ordenación Pesquera. (*Regional Fisheries Management Organizations*).
OSPESCA	Organización del Sector de Pesca y Acuicultura de la Región Central Istmo Americano. (*Organization of the Fisheries and Aquaculture Sector of the Central American Isthmus*).
GDP	Gross Domestic Product
PNMB	Parque Nacional Marino Las Baulas. (*Las Baulas Marine National Park*).
ETP	Eastern Tropical Pacific.
PUS	Papagayo Upwelling System.
SICA	Sistema de Integración Centroamericana. (*Central American Integration System*).
SINAC	Sistema Nacional de Áreas de Conservación de Costa Rica. (*National System of Conservation Areas of Costa Rica*).
t	Tons.
TBF	The Billfish Foundation.
µm	micrometers.
UICN	Unión Internacional para la Conservación de la Naturaleza (*International Union for the Conservation of Nature*).
UNESCO	Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura (*United Nations Educational, Scientific and Cultural Organization*).
UCR	University of Costa Rica.
US$	United States dollar.
UV	Ultraviolet.
OUV	Outstanding Universal Value.
ATBA	Areas to be Avoided.
ITCZ	Intertropical Convergence Zone.
EEZ	Exclusive Economic Zone.

I. INTRODUCTION

The Eastern Tropical Pacific (ETP) extends from the tip of the Peninsula of Baja California, in the northwest of Mexico, to the south of Peru; and from the eastern limit of the North Pacific Gyre (about 120° W) to the American continent in the east (Kessler, 2006).

The region presents an unusual biological environment of great importance, due to the presence of large marine currents, the emergence of cold waters rich in nutrients, coastal wind jets, low iron contributions and inadequate ventilation of waters below the thermocline (area where the temperature changes abruptly). These unique environmental characteristics favor, both the population growth of plankton, and of larger organisms (Fiedler and Philbrick,199; Fiedler and Lavín, 2006; Lavín *et al*., 2006).



Hammerhead shark
Sphyrna lewini

Within this region is the TDCR (Thermal Dome of Costa Rica), an oceanographic process generated mainly by the proximity to the surface of the Northern Equatorial Counter Current (NECC) flank, as well as by seasonal changes in interconnected phenomena: coastal wind jets, eddies, the Intertropical Convergence Zone (ITCZ), the geostrophic balance and the upwelling of the thermocline close to 10 ° N (Fiedler, 2002, Kessler, 2006). Unlike other upwellings, the Dome is unique because it is formed by a coastal wind jet (Figure 1; Fiedler *et al*., 2017).

The primary and secondary productivity, as well as the decomposition of the biomass, are relatively high in the Dome (Lavín *et al*., 2006). As a result, important ecological processes (such as the maintenance of threatened populations and carbon sequestration), as well as economic activities (such as fisheries and tourism), are linked to this oceanographic phenomenon.

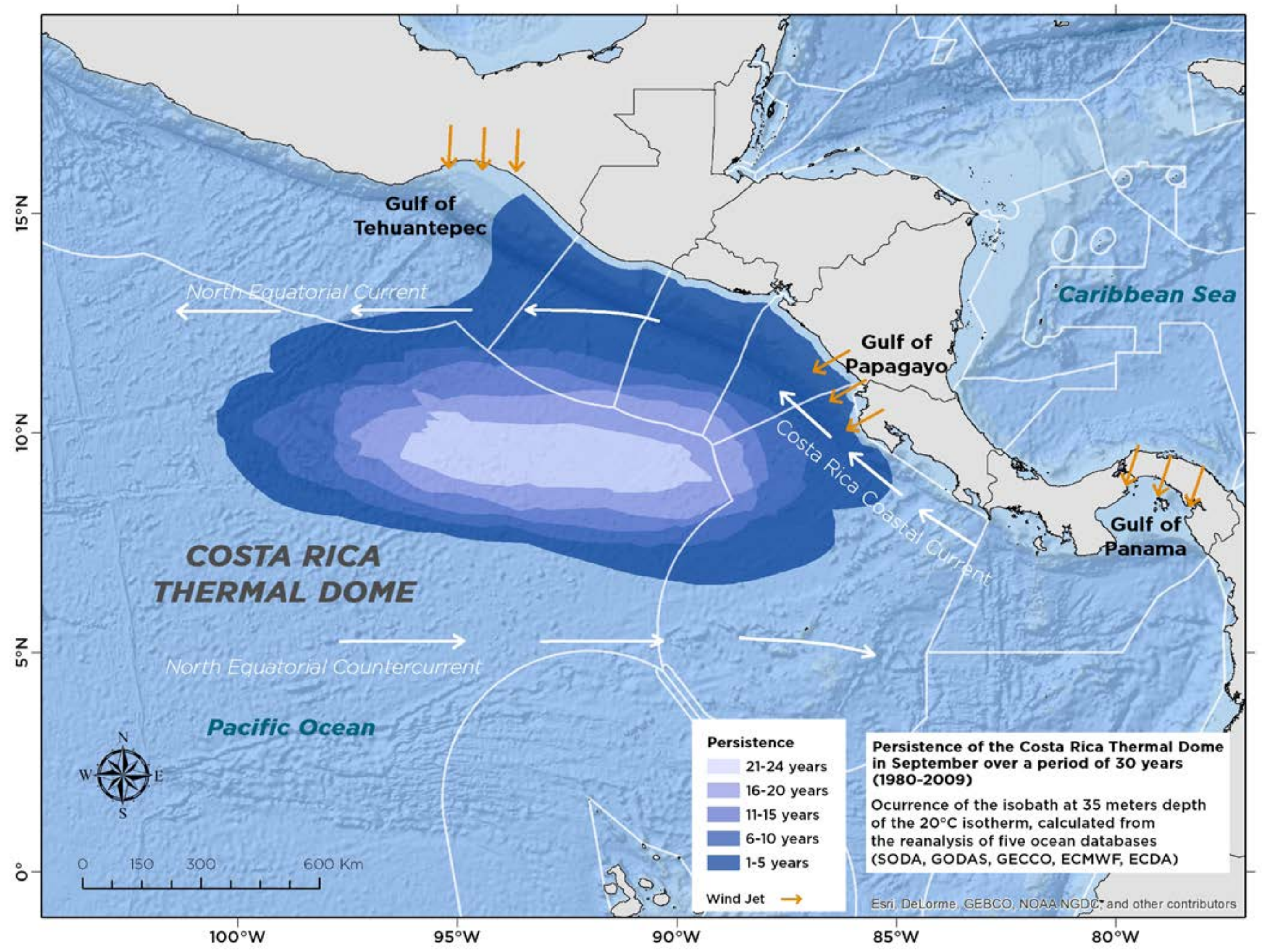


Figure 1. Main marine currents and winds that influence the dynamics of the TDCR

History of the Dome

The Dome was first observed in 1948 (Wyrtki, 1964) and was described in 1958 by the researcher of the Inter-American Tropical Tuna Commission (IATTC), Townsend Cromwell (Cromwell, 1958).

Cromwell located this important upwelling at 9 ° N and 90 ° W, off the coast of Costa Rica, so he called it the Thermal Dome of Costa Rica (Cromwell, 1958).

The Dome, due to its ecological importance, has been subject to a large number of scientific investigations by the IATTC, the NOAA (National Oceanic and Atmospheric Administration), universities (Oregon State University, Stanford University, University of Costa Rica, National University, University of Miami, among others) and various non-governmental organizations (NGOs, MarViva Foundation, Marine Turtle Restoration Program, The Leatherback Trust, among others).

As a result of this large amount of research, the relevance of the Dome has been recognized worldwide by multiple organizations that have included it in their classification of relevant sites outside national jurisdictions:

CBD: Marine Areas of Biological or Ecological Importance

The designation of Ecologically or Biologically Significant Marine Areas (EBSAs) is made within the Convention on Biological Diversity (CBD). Since 2004, this multilateral organization has discussed the conservation of marine biodiversity in Areas Beyond of the National Jurisdiction (ABNJ).

In 2012, the Government of Costa Rica approved the initiative of MarViva Foundation to propose the Dome as an EBSA, in the Regional Workshop of the Tropical and Tempered Eastern Pacific of the CBD that took place in the Galapagos Islands in that same year. This workshop recognized the potential of the Dome as an EBSA, including it within its work report. The Subsidiary Body on Scientific, Technical and Technological Advice of the CBD endorsed this potential under the name of Papagayo Upwelling System (PUS), which covers only a section of the total area of the Dome. Finally, at the 2014 Conference of the Parties to the CBD, the plenary approved the designation of the PUS as an EBSA.

The PUS extends from the southern Pacific coast of Nicaragua and northern Costa Rica, to the international waters that cover the central part of the Dome and cover an area that fluctuates seasonally between 2,000-200,000 square kilometers (km^2) (Figure 2). The designation of the PUS as an EBSA could promote future investments of technical and financial resources, as well as the creation and implementation of a governance system that guarantees the conservation and sustainable management of marine resources in this area.

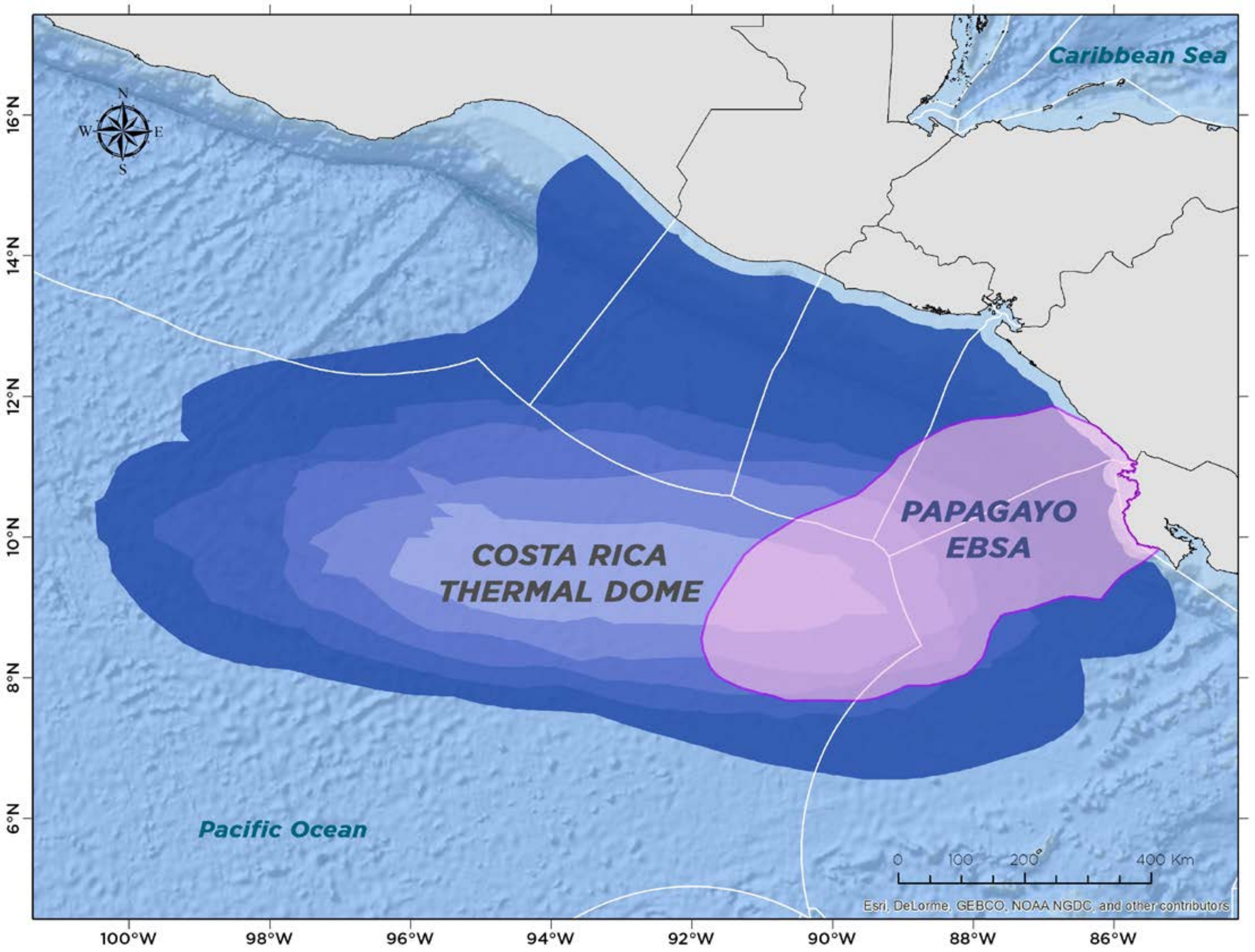


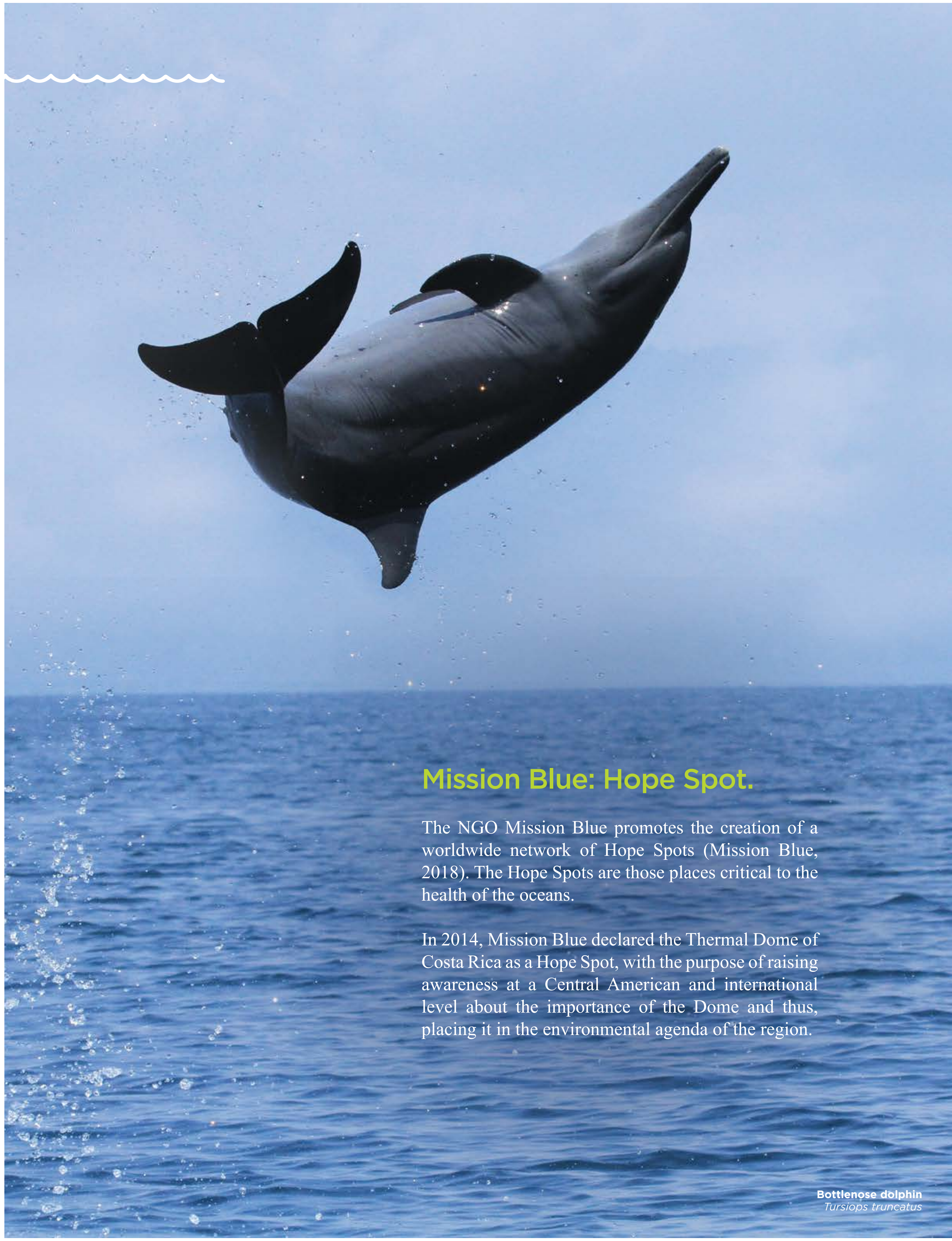
Figure 2. EBSA of the Papagayo Upwelling System.

UNESCO: Site of World Heritage

The World Heritage category is conferred by the United Nations Educational, Scientific and Cultural Organization (UNESCO) on specific sites characterized by cultural, historical, scientific or other significance. These sites are considered important for the collective interest of humanity for its Outstanding Universal Value (OUV) and its designation seeks to conserve these sites for posterity (UNESCO, 2016).

A workshop of experts, in 2015, defined five priority sites to be considered World Heritage in the ABNJ: The Hydrothermal Field of the Lost City, the Thermal Dome of Costa Rica, the White Sharks Cafe, the Sargasso Sea and the Atlantis Bank.

The Dome was considered a priority site in ABNJ because it is an oceanic oasis, an upwelling system that results in a highly productive area and a critical habitat that provides unique spawning sites, migratory routes and feeding sites to multiple endangered species. and of economic importance (UNESCO, 2016).

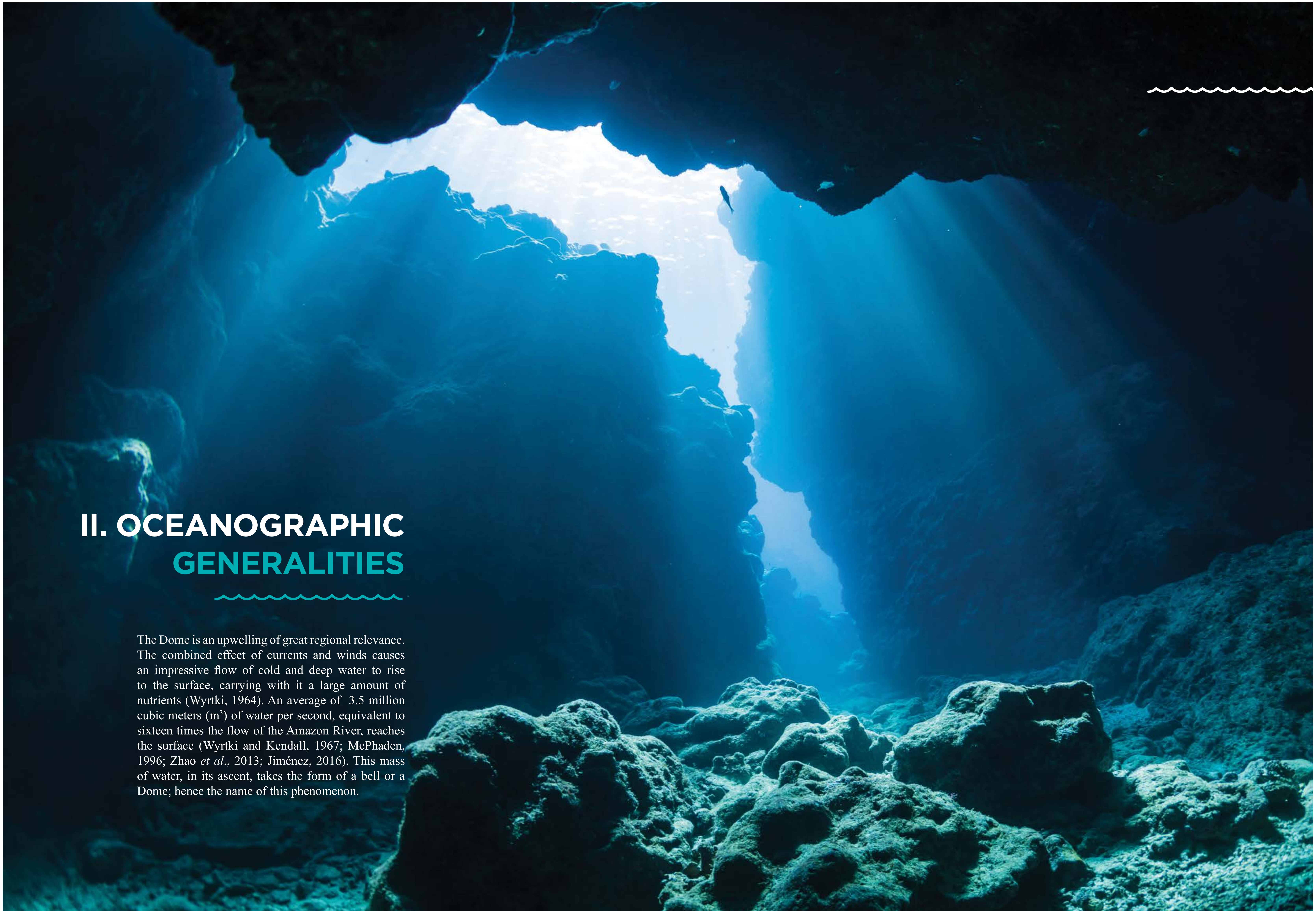


Mission Blue: Hope Spot.

The NGO Mission Blue promotes the creation of a worldwide network of Hope Spots (Mission Blue, 2018). The Hope Spots are those places critical to the health of the oceans.

In 2014, Mission Blue declared the Thermal Dome of Costa Rica as a Hope Spot, with the purpose of raising awareness at a Central American and international level about the importance of the Dome and thus, placing it in the environmental agenda of the region.

Bottlenose dolphin
Tursiops truncatus



II. OCEANOGRAPHIC GENERALITIES

The Dome is an upwelling of great regional relevance. The combined effect of currents and winds causes an impressive flow of cold and deep water to rise to the surface, carrying with it a large amount of nutrients (Wyrtki, 1964). An average of 3.5 million cubic meters (m^3) of water per second, equivalent to sixteen times the flow of the Amazon River, reaches the surface (Wyrtki and Kendall, 1967; McPhaden, 1996; Zhao *et al*., 2013; Jiménez, 2016). This mass of water, in its ascent, takes the form of a bell or a Dome; hence the name of this phenomenon.

Annual Behavior

The Dome shows an annual behavior, in which its position and size vary according to the behavior of phenomena such as currents, winds and the displacement of the ITCZ throughout the year (Hofmann *et al*., 1981; Umatani and Yamagata, 1991; Fiedler, 2002; Jiménez, 2016; Fiedler *et al*., 2017).

The Dome begins its formation usually between January and February, when strong trade winds cross Lake Nicaragua, in the direction of San Juan del Sur, and the Gulf of Papagayo. These winds (called the Papagayo jet) occur at the same time as other jets occur in Tehuantepec and Panama. (Fig. 3). At this time, the Dome is located closer to the coast, with diameters between 200 and 300 kilometers (km).

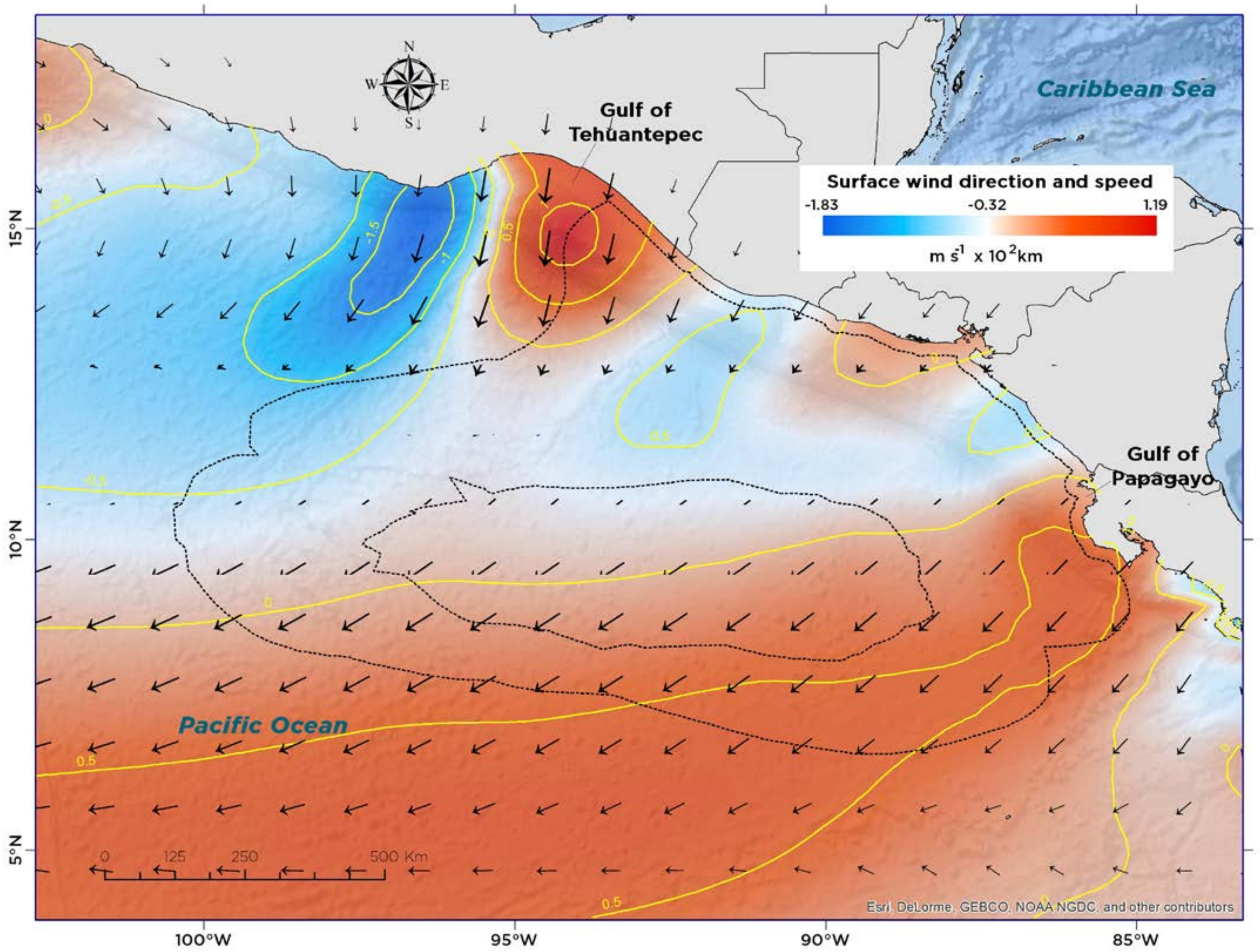


Figure 3. Climatology of the superficial winds between February and April for the 1999-2009 period (adapted from Fiedler *et al*., 2017).

The surface temperatures of the water are colder in coastal regions where these jets reach the Pacific Ocean (Fig. 4). The thermocline, consequently, is shallower in these coastal regions (Fig. 5).

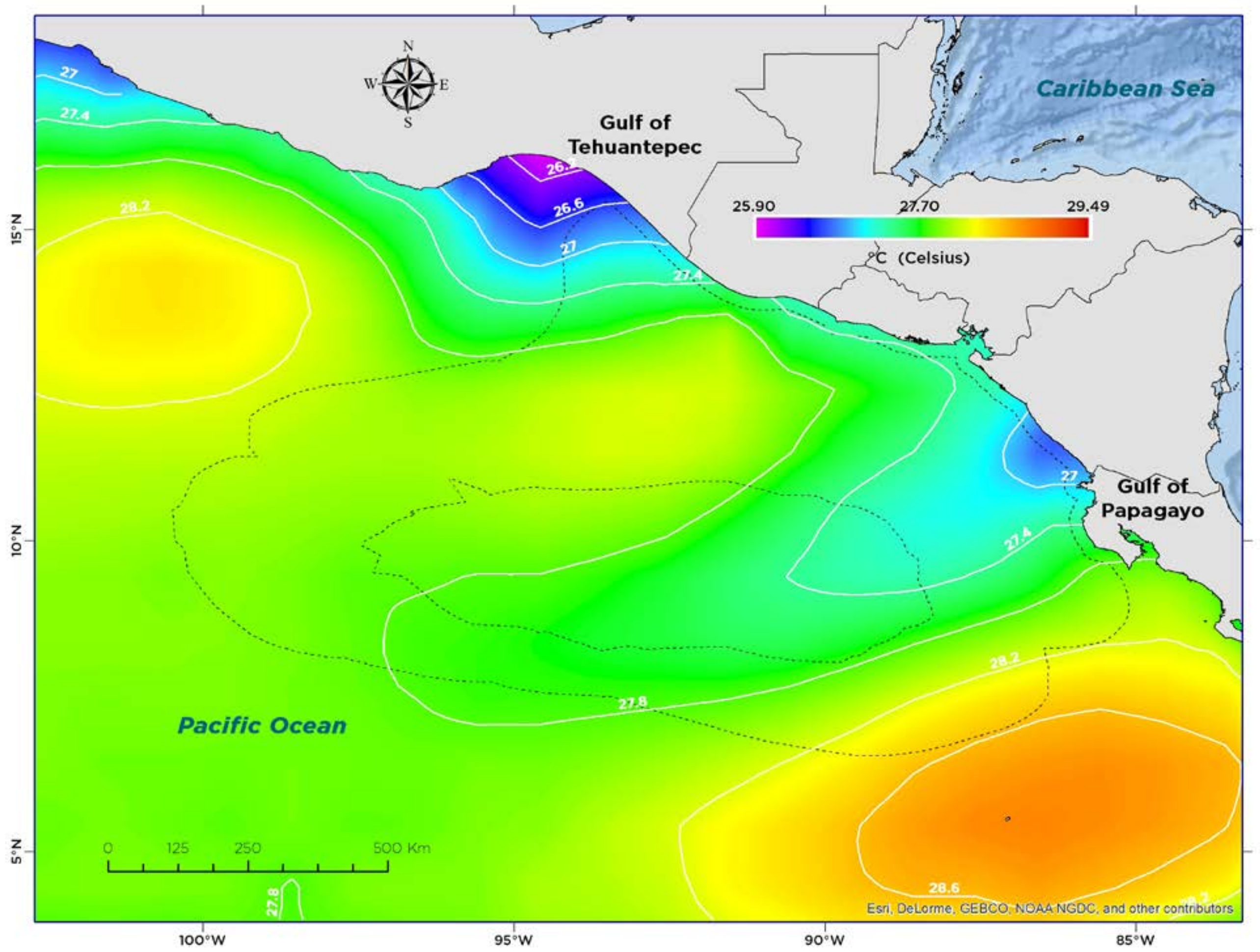


Figure 4. Average superficial sea temperature between February and April (adapted from Fiedler *et al*., 2017).

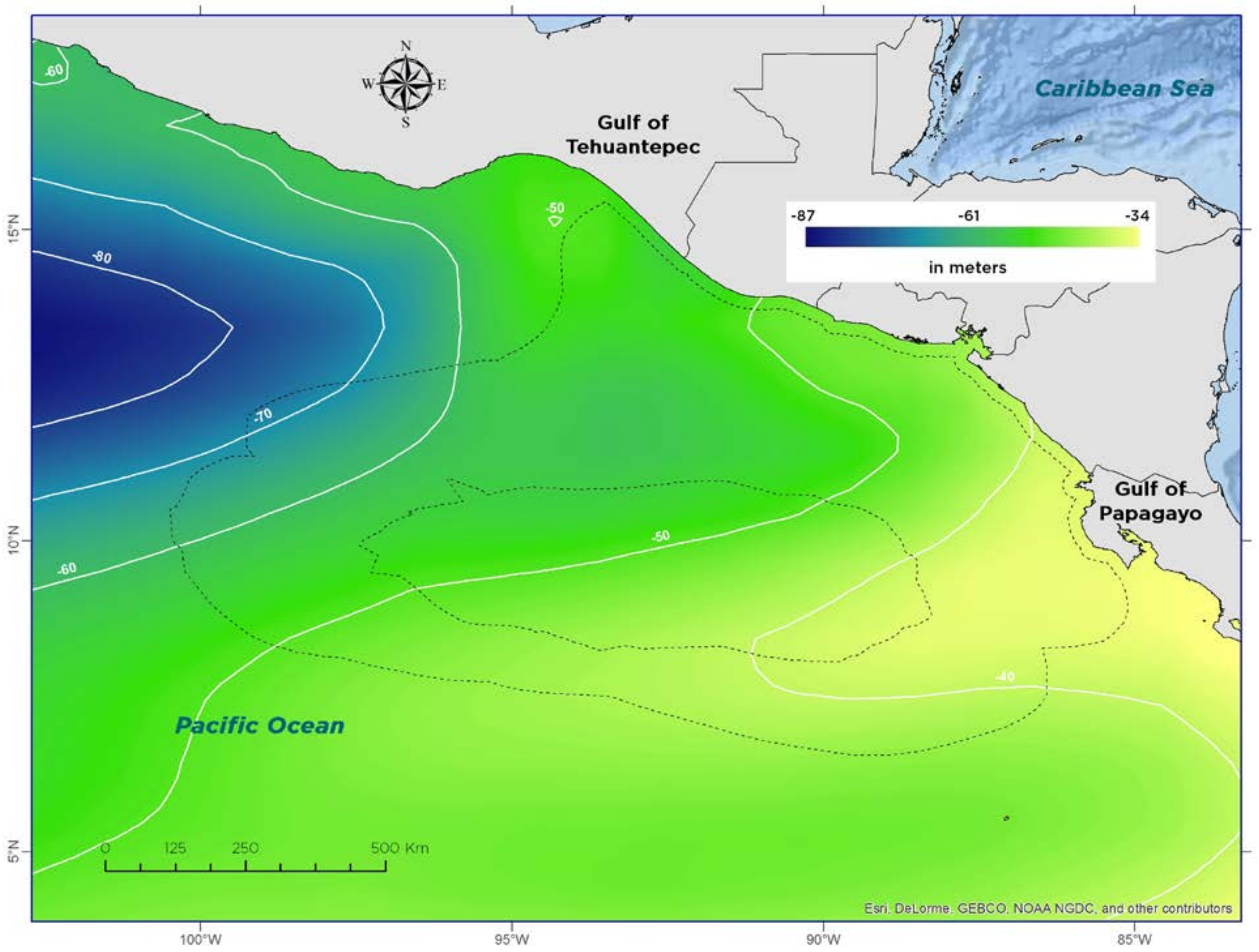


Figure 5. Average depth of the thermocline between February and April (adapted from Fiedler *et al*., 2017).

Unlike other processes in the region, during May and June, as the winds lose strength, the Dome separates from the coast, migrating north and into deeper and farther waters, on the back of the NECC, whose shallow position maintains the upwelling process. In this period its diameter extends between 300 and 500 km.

Between August and November, the winds weaken in the northern region, as the ITCZ moves over the region (Fig .6).

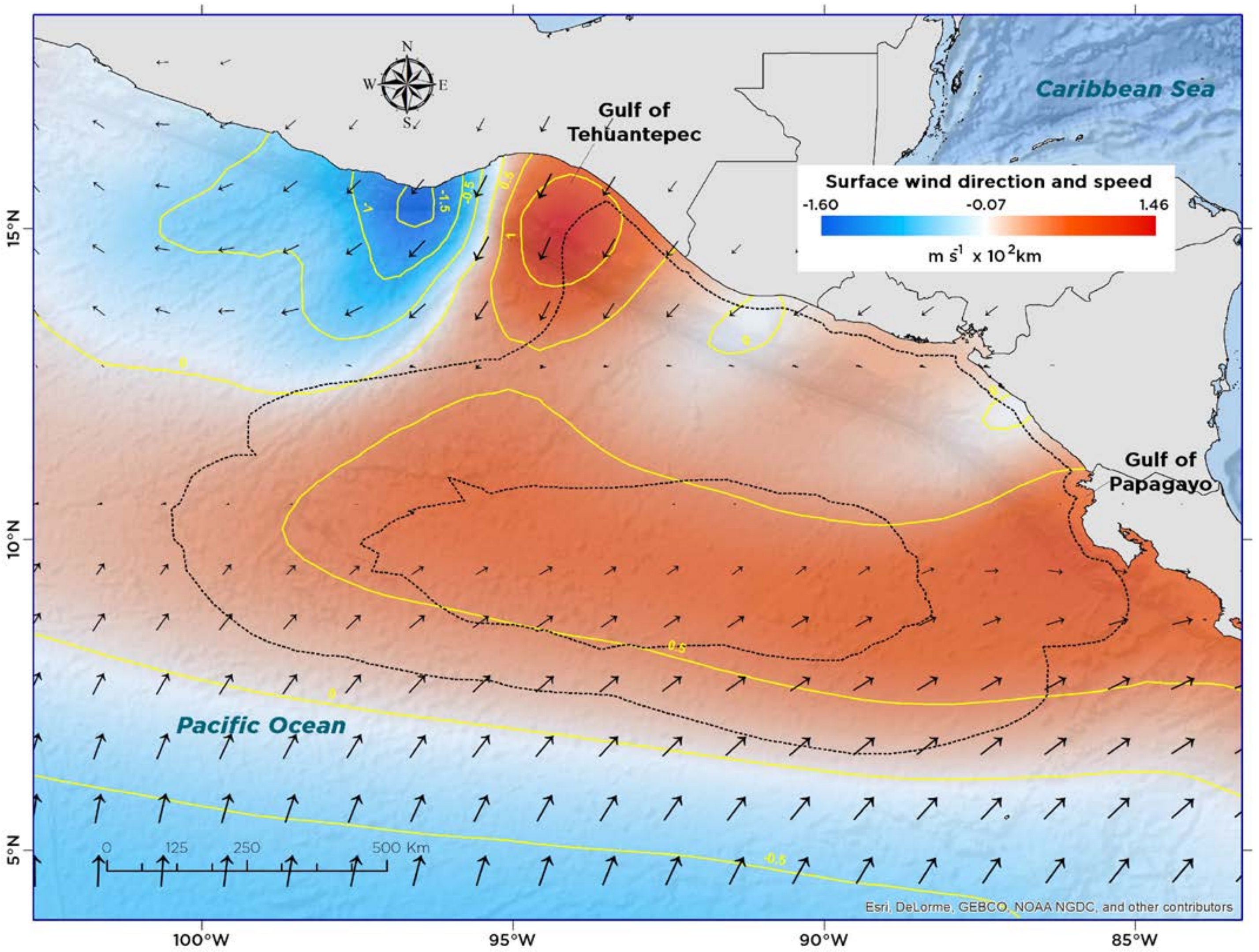


Figure 6. Average speed and direction of winds between August and November in the Dome region (adapted from Fiedler *et al*., 2017).

For this time, the core of the Dome is clearly located in international waters, maintained by the NECC that approaches the surface. The surface waters around the core are cold since the thermocline is less than 30 m deep (Fig. 7). The Dome, in this phase of maximum extension, reaches a diameter of up to 1,000 km.

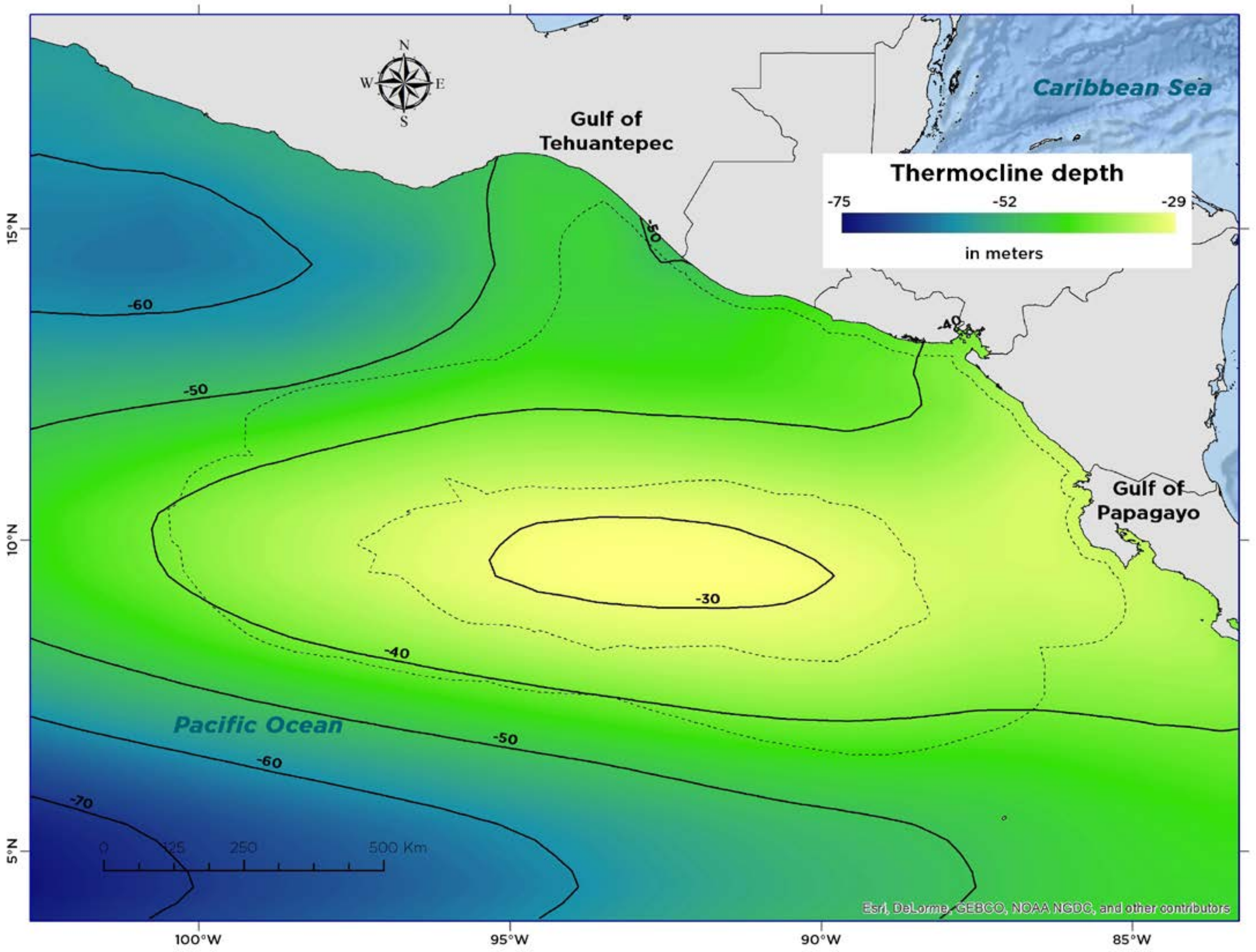
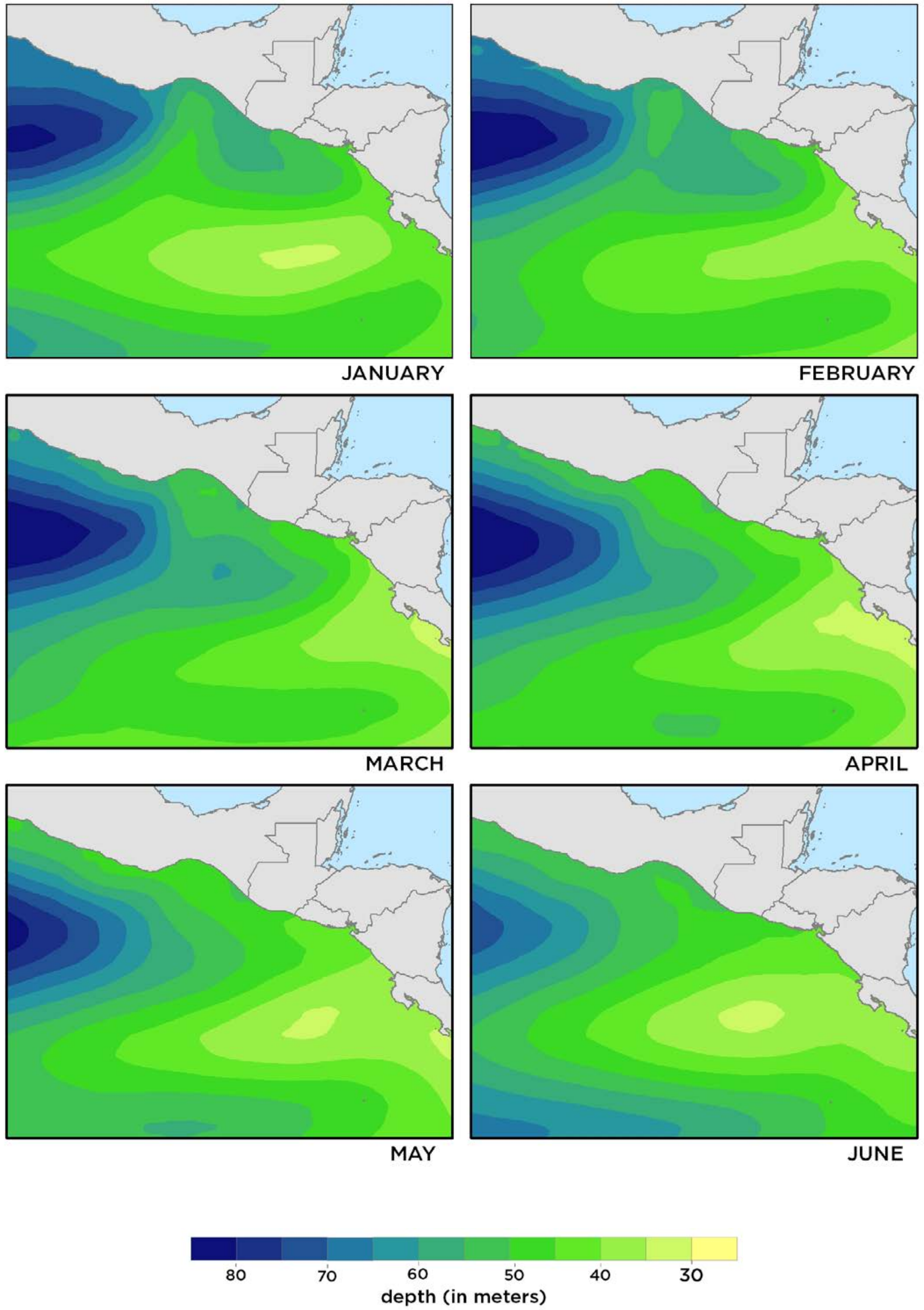


Figure 7. Average depth of the thermocline from August to November (adapted from Fiedler *et al*., 2017).

Between November and early January, the Dome is markedly reduced, as the warm eddies associated with the southward migration of the ITCZ, displaces warm water over the Dome region, "sinking" the thermocline below the photic zone and consequently reducing the primary productivity in the region (Wyrtki, 1964; Umatani and Yamagata, 1991; Muller-Karger and Fuentes-Yaco, 2000; Fiedler, 2002; McClain *et al*., 2002; Brenes *et al*., 2008; Jiménez, 2016)

The extension of the Dome also fluctuates from year to year. An analysis with different predictive systems (Fiedler *et al*., 2017) established the location and maximum limits of the Dome for the period 1980-2009, based on the isotherm of 20˚C at 35 m depth (Fig. 8). An overlap of these monthly maps allowed identifying the areas of greatest persistence of the Dome during the period analyzed (Fig. 8). This analysis allows us to reach two conclusions of particular importance for the countries of the region: 1) for more than 20 of the 30 years analyzed, the core of the Dome was located at the high seas from June to February, outside the Exclusive Economic Zone (EEZ) of the Central American countries and 2) in at least 6 of the 30 years analyzed, the Dome covered part of the jurisdictional waters of all the countries of the region, with the exception of Panama (Jiménez, 2016).



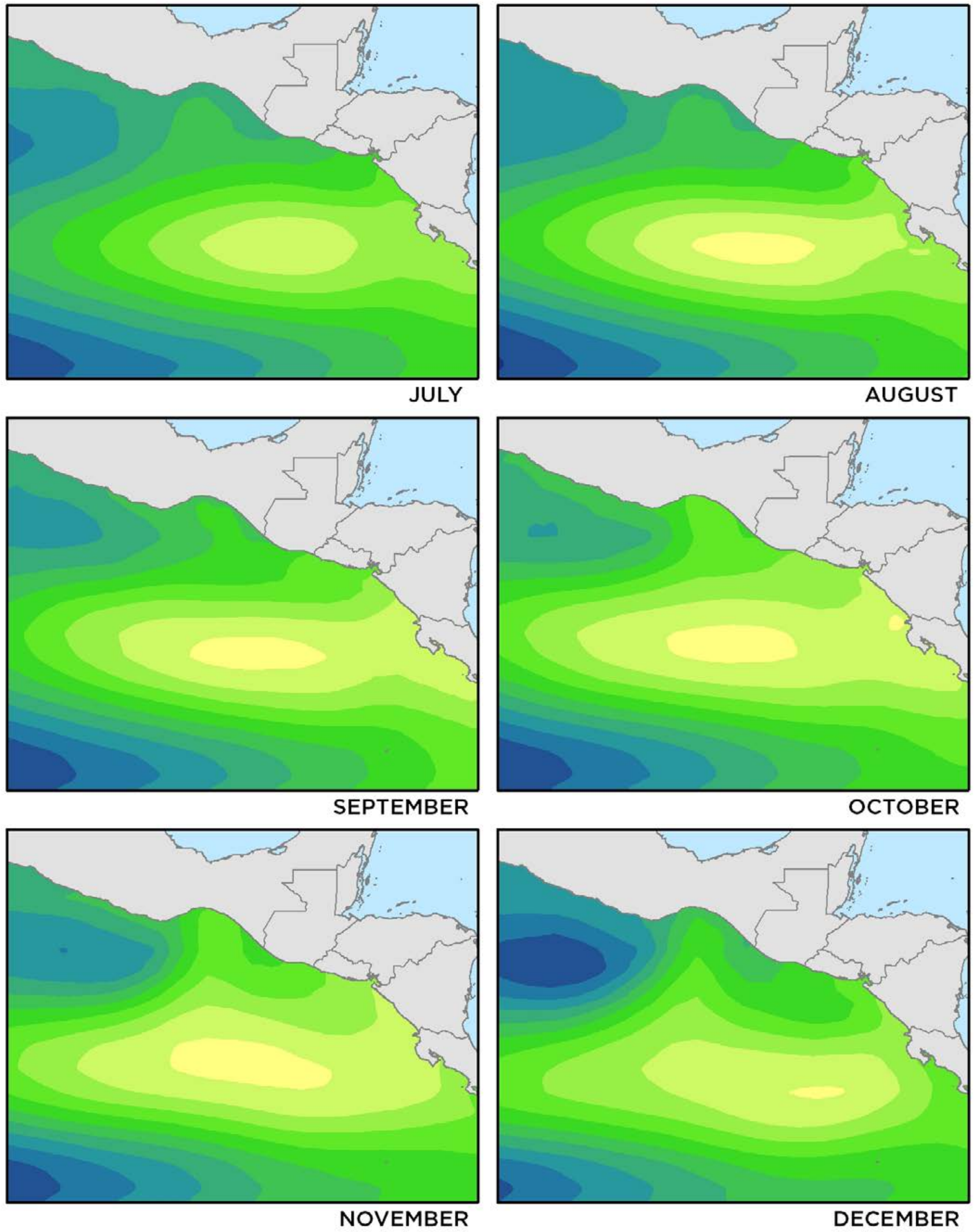
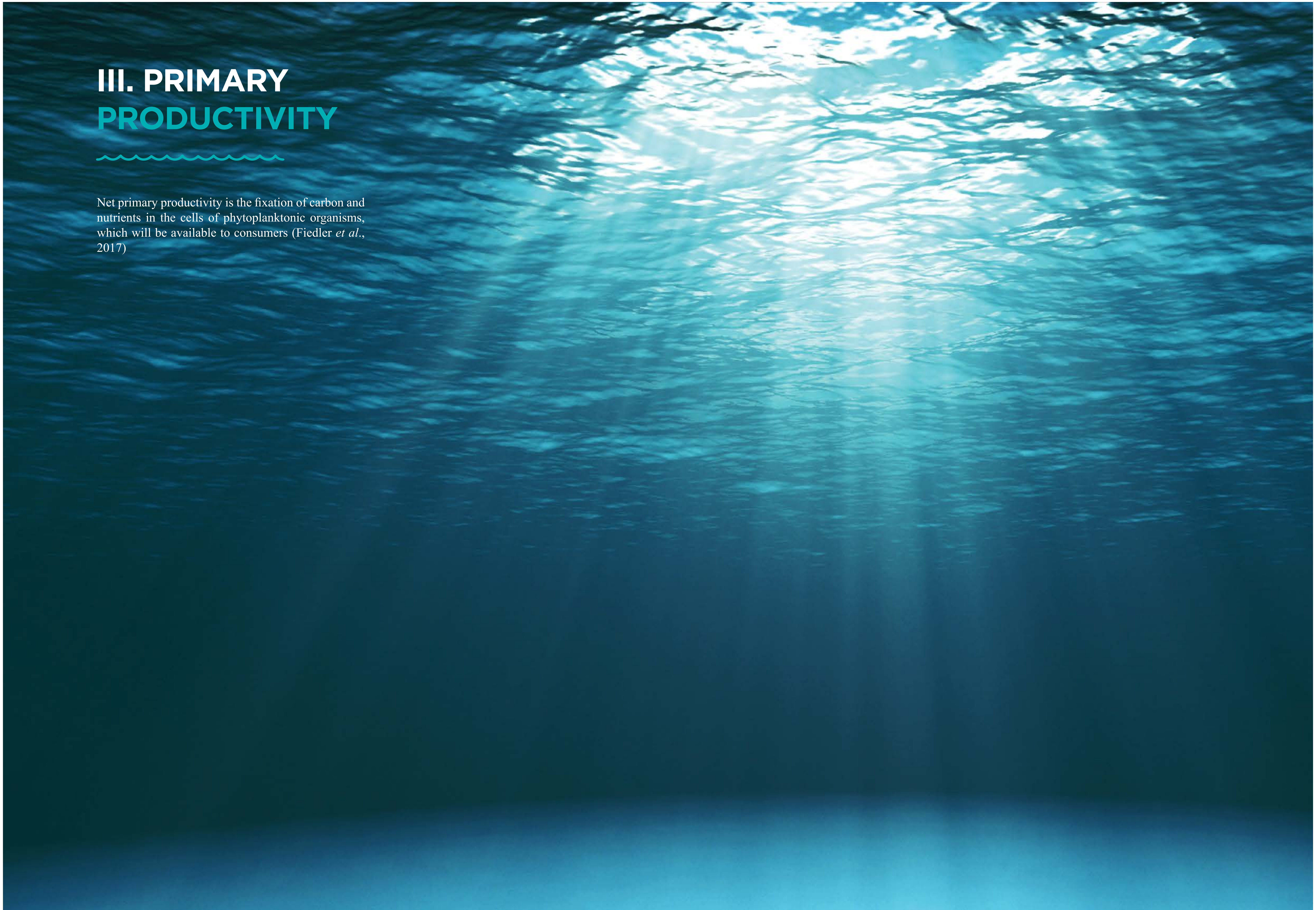


Figura 8. Depth of the thermocline over an average year, using data from 1980-2015 (adapted from Fiedler *et al.*, 2017).

III. PRIMARY PRODUCTIVITY

Net primary productivity is the fixation of carbon and nutrients in the cells of phytoplanktonic organisms, which will be available to consumers (Fiedler *et al.*, 2017)



This productivity increases when the supply of nutrients reach the layer of water where light penetrates (photic zone). The upwelling of the Dome brings high concentrations of nutrients to the photic zone, which decrease as the water approaches the surface, indicating its consumption by the phytoplankton in the water column (Fig. 9) (Broenkow, 1965; Jiménez, 2016)

Unlike other oceanic upwellings, the primary productivity in the Dome is mainly associated with autotrophic picoplankton [minuscule organisms, less than 2 microns (µm)], which are concentrated near 20 m depth (Li *et al*., 1983; Saito *et al*., 2005; Ahlgren *et al*., 2014; Gutiérrez-Rodríguez *et al*., 2014). The presence of eukaryotic phytoplankton (larger organisms with a defined nucleus), seems to be limited in the Dome due to the low concentrations of iron and zinc (Franck *et al*., 2003; Landry *et al*., 2015).

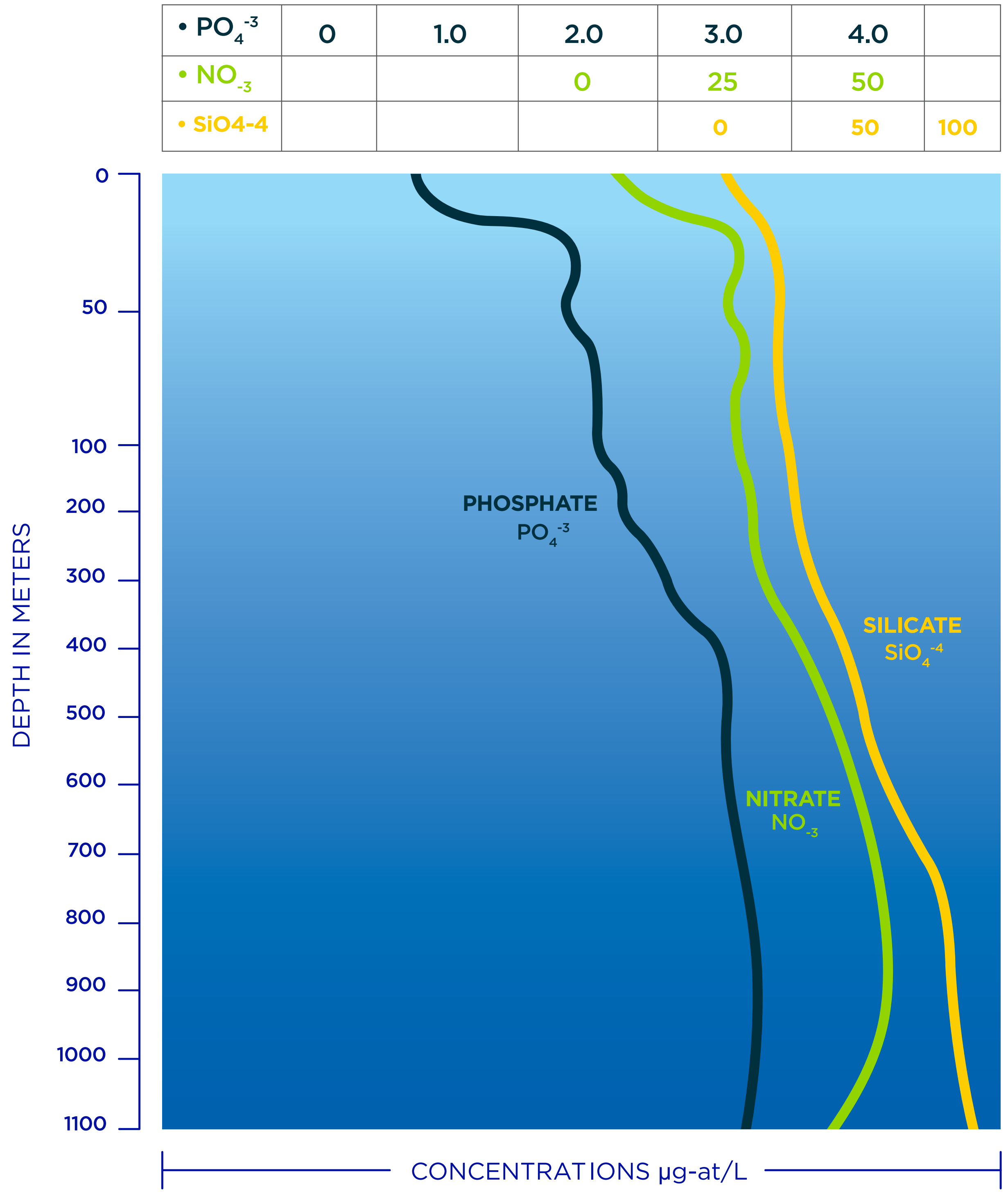


Figure 9. Average concentration of nutrients in the TDCR along the water column (adapted from Jiménez, 2016).

The Dome presents unusually high densities of picoplankton formed by cyanobacteria of the genera *Synechococcus* and *Prochlorococcus* (Fig.10; Li *et al*., 1983; Saito *et al*., 2005). The reported densities of these organisms [3.7 x 106 and 7 x 105 cells per milliliter (ml), respectively], are the highest in the world and appear to be associated with the high concentrations of cobalt in the region (Saito *et al*., 2005; Ahlgren *et al*., 2014). Cyanobacteria, known as blue-green algae, are able to obtain energy through photosynthesis and are the only photosynthetic prokaryotic organisms capable of producing oxygen (Burkholder, 2002).

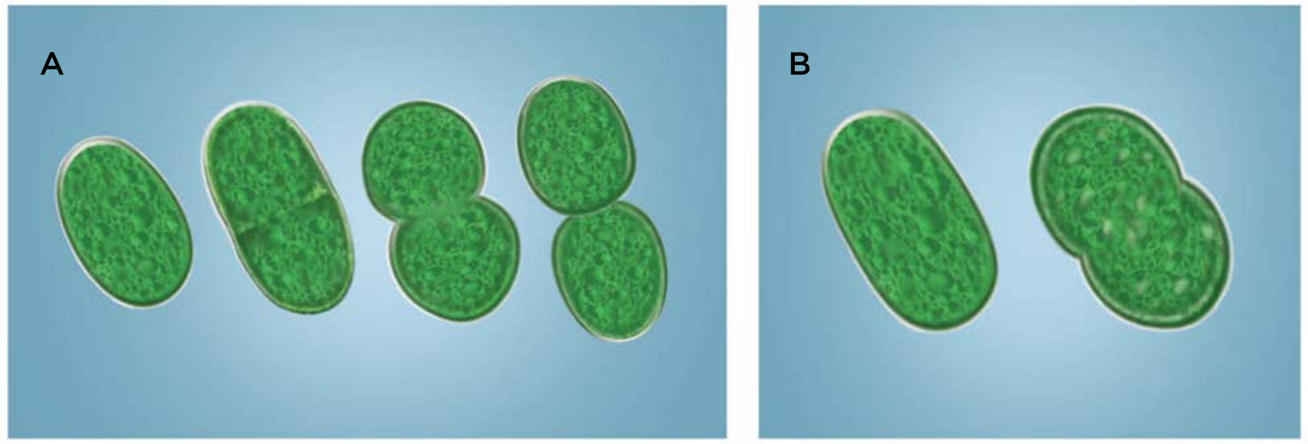


Figure 10. Cyanobacteria *Synechococcus* (A) and *Prochlorococcus* (B) are responsible for most of the primary productivity in the TDCR (taken from Jiménez, 2016).

The primary productivity of the region follows the annual cycle of the Dome. Between February and April, primary productivity is high in coastal waters, as a response to the mixture caused by winds that carry deep water to the surface. From August to November the primary productivity is higher in the High Seas, due to the upwelling of deep waters caused by the NECC, which approaches only 25 m deep at 90° west longitude (Fig. 11; Fiedler, 2002; Vilchis *et al*., 2009; Fiedler *et al*., 2017). During periods of El Niño, large waves of warm water are displaced by winds from the

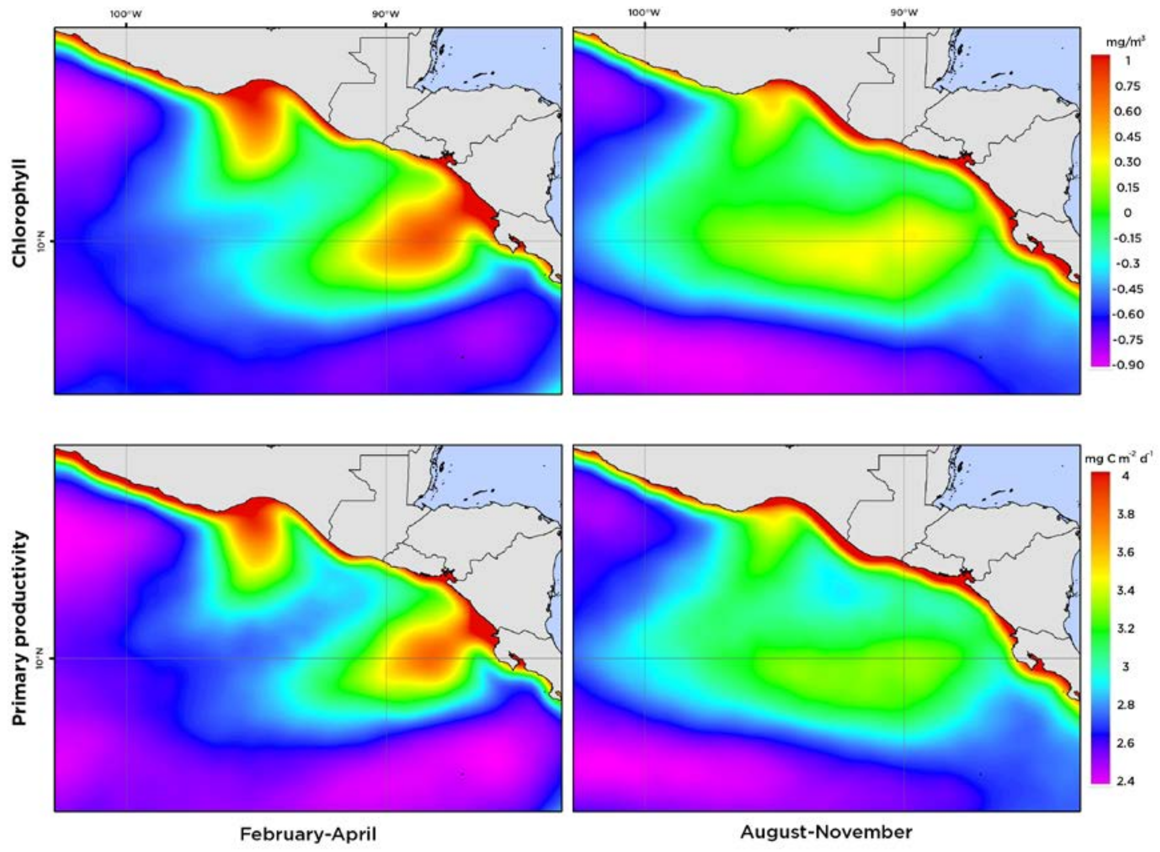
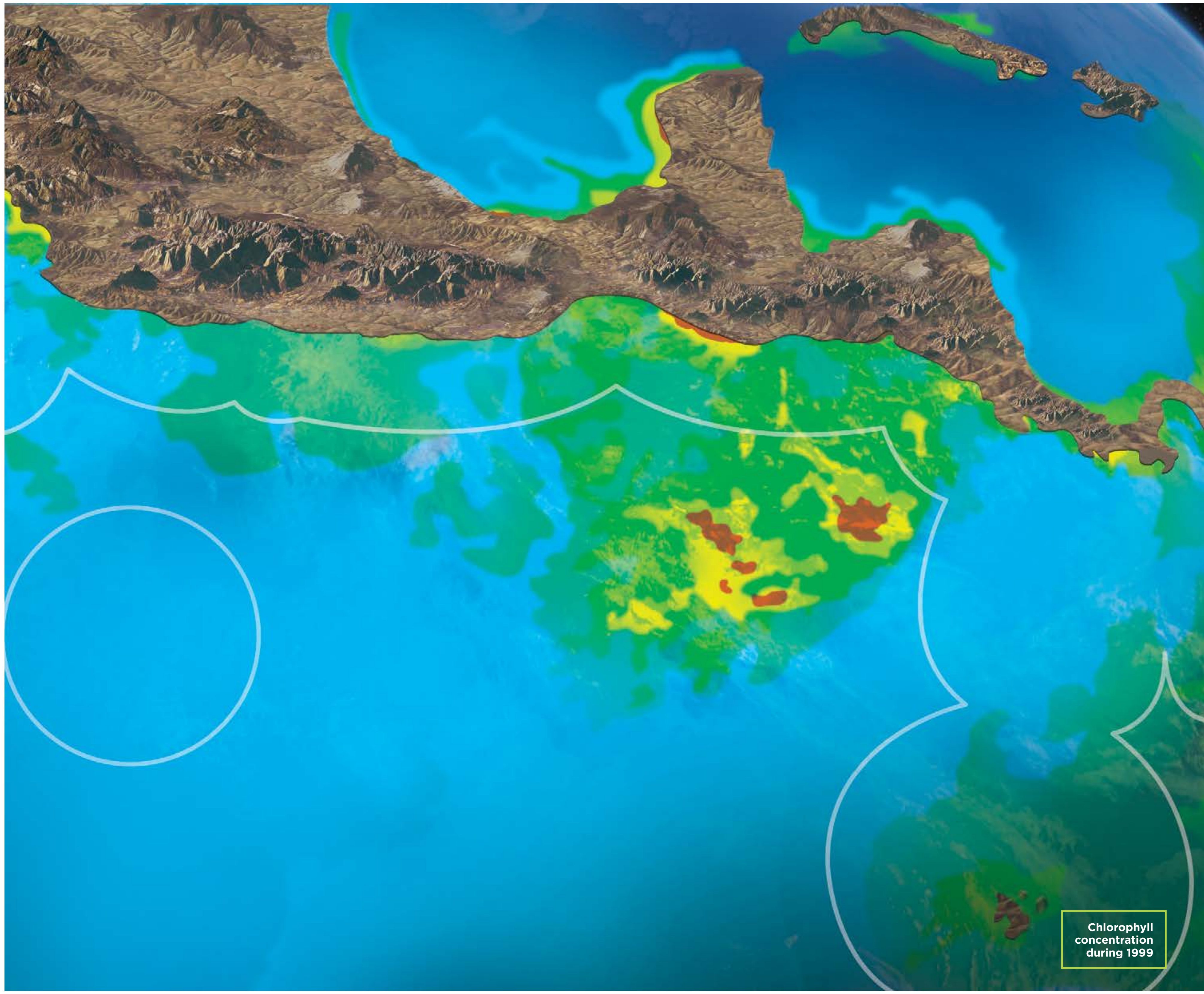
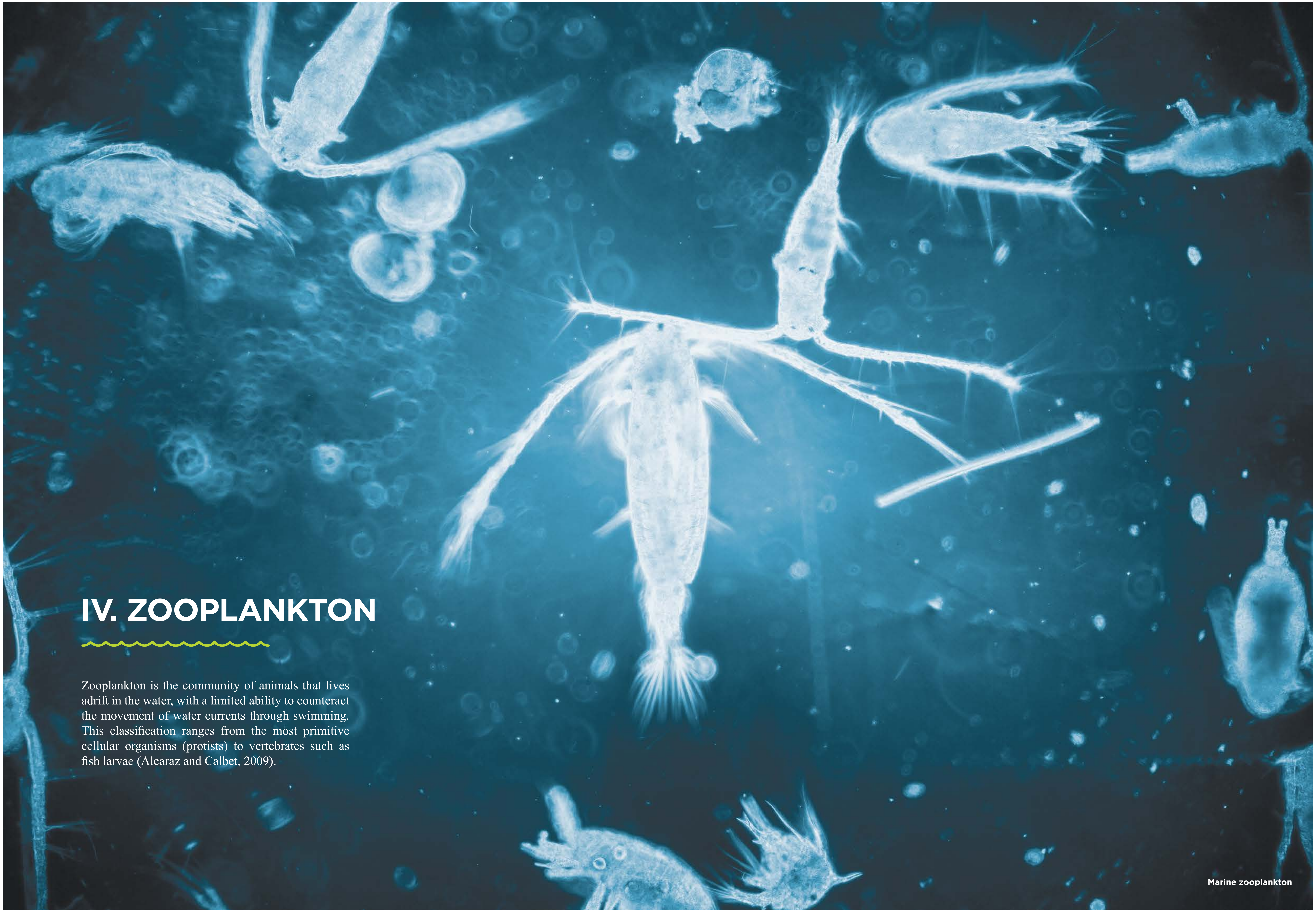


Figure 11. Primary productivity and mean chlorophyll concentration in the TDCR region for the 1999-2016 period (taken from Fiedler *et al.*, 2017).

Western Pacific to the East (Alfaro and Lizano, 2001; Alexander *et al.*, 2012). These transfers cause the cold waters to sink outside the photic area, away from sunlight's influence (Alexander *et al.*, 2012). This in turn causes the abundance and diversity of phytoplankton species to decrease, which reduces the region's primary productivity (Jiménez, 2016).


Chlorophyll concentration during 1999



IV. ZOOPLANKTON

Zooplankton is the community of animals that lives adrift in the water, with a limited ability to counteract the movement of water currents through swimming. This classification ranges from the most primitive cellular organisms (protists) to vertebrates such as fish larvae (Alcaraz and Calbet, 2009).

Marine zooplankton

In the Dome there have been 24 species reported of cnidarians and hydromedusas, distributed in 19 genera; 48 species of siphonophores belonging to 24 different genera; 23 species of polychaeta annelids distributed in 11 genera; 30 species and 11 mollusk forms in 14 genera of gastropods and one species of pelecypod; paralarvae of 15 species of cephalopods; 41 species belonging to 26 genera of copepods; 18 species of amphipods distributed in 18 genera; 13 species of chaetognath in 3 genera; 25 species of decapods in 21 genera; 14 species of stomatopod in 4 genera and 40 species of tintinnids in 27 genera (Jiménez, 2016).

Despite its limited swimming capacity, zooplankton performs vertical rhythmic (day-night) migrations of hundreds of meters, mostly to feed on surface waters during the night (Alcaraz and Calbet, 2009).

12A

12B

Figure 12. 12ª subeucalanus subtenuis 12b eufausiacea (crustacean malacostracea)

The distribution of the biomass of zooplankton and micronekton (small organisms with swimming capacity), between the surface and depths of up to 1,000 m, is influenced by factors such as the distribution of primary productivity, salinity and oxygen concentration. However, the depth of the thermocline and the distribution of oxygen in the water column seem to have the greatest influence of all the physical factors on the distribution of species in the water column (Sameoto, 1986).

In the Dome, the meroplankton biomass and the number of copepods is about twice as high and three to four times higher, respectively, than in other nearby sites, which seems to be influenced by the high primary productivity of the region (Sameoto, 1986; Suárez and Gasca, 1989). At the same time, there is little wealth of species, since the upwelling areas tend to be dominated by herbivorous organisms (Suárez and Gasca, 1989).

The biomass of euphausiids in the Dome is considered the highest recorded for the ETP and is associated with upwelling. The adult euphausiids are concentrated during the day between 300 and 350 m deep, while the juveniles are located between 80 and 170 m. During the night, the concentration of euphausiids migrates towards the surface, between 20 and 30 m (Sameoto *et al.*, 1987; Fernández-Álamo and Färber-Lorda, 2006).

Whale shark
Rhincodon typus

Are microplastics a threat for the biodiversity of the Dome?

David Edward Johnson
GOBI

Microplastics are small pieces [<5 mm (mm) in diameter)], which were produced for a specific purpose (abrasive or cosmetic) or generated from larger pieces that were fragmented by ultraviolet (UV) radiation or physical abrasion. The transfer of chemicals and contaminants from ingested plastics into animal tissues is the focus of research. However, it is believed that microplastics of very small sizes (nanoparticles) can cross cell membranes and present an ecotoxicological risk (GESAMP, 2015).

The Papagayo wind jet and its associated whirlpools are likely to drive marine litter away from the coast, where it will circulate and decompose into microplastics in the Dome. Ingested garbage, including microplastics, can affect the physiology of whales, dolphins, sea turtles, birds, fish, invertebrates and other filtering organisms. Although there are few investigations to evaluate the risk of plastic pollution in the PTO, microplastics are certainly present, so it is necessary to improve the evaluations and the awareness of the impact of plastics and microplastics.

In an expedition to the Dome area (Johnson *et al.*, 2018), 13 samples of zooplankton were analyzed, in which 206 fibrous plastic particles were found, probably of terrigenous origin. This shows not only the connectivity between the Dome and the coastal areas, but also the extensive impact of plastics on the oceans.

At the national and regional level, important actions can be carried out to raise awareness and educate the population, as well as working on the promotion of behavioral changes that promote reduction, reuse and recycling. The design of products must be modified to turn plastics into a valuable resource at the end of its life cycle and generate changes in the respective national legislations.

It is key to work with different sectors to transform consumption patterns and have a regulatory framework that allows the integral management of waste, extending responsibility to the producer for the life cycle of their products. Other actions include specific institutional purchasing regulations, incentives for the substitution of single-use plastics, publicizing voluntary commitments, encouraging relevant scientific research and communicating the results of the activities.

More than 80% of Marine pollution Comes from land sources

V. MARINE MAMMALS

At least 30 species of cetaceous have been identified in the Dome (Au and Perryman, 1985; Ballance *et al.*, 2006; Fiedler *et al.*, 2017; Johnson *et al.*, 2018). Three of them, the common dolphin (*Delphinus delphis*), the striped dolphin (*Stenella coeruleoalba*) and the blue whale (*Balaenoptera musculus*), with a distribution closely linked to the Dome (Ballance *et al.*, 2006; Fiedler *et al.*, 2017). The majority of the mammals found in the Dome can travel from tens to hundreds of kilometers a day, so it is important to consider this high mobility and vast habitat, when proposing regional conservation measures (Ballance *et al.*, 2006). Through these migrations, the Dome is closely connected to other ocean regions and the Central American coast. The effective conservation of these highly migratory marine species requires international cooperation and management, as well as a lot of scientific information on the use of this habitat by the species. (Johnson *et al.*, 2018).

Blue whale
Balaenoptera musculus

Blue whale
Balaenoptera musculus

Blue whale

The blue whale (*Balaenoptera musculus*) is the largest animal that has inhabited the planet, reaching more than 30 m in length and at least 180 tons (t) in weight (Reeves *et al*., 2002).

Although it is classified as an endangered species, its populations tend to increase (UICN, 2012). In the northeast Pacific it is estimated that its population consists of about 3,000 individuals; while in the Southeast Pacific Ocean, in Peruvian and Ecuadorian waters, about 1,000 individuals are estimated (Best *et al*., 2003; Calambokidis and Barlow, 2004). A study conducted in the equatorial zone of the Eastern Pacific during the months of July and December, calculated an abundance of 1,400 blue whales, composed of individuals from both the northern and southern populations (Wade and Gerrodette, 1993).

Blue whales from the west coast of the United States and Canada migrate to Baja California and the Dome, traveling thousands of kilometers each year during the northern winter (Fig. 13). Migratory routes are generally kept close to the continental margin, with occasional visits to areas far from the coast (Bailey *et al*., 2009).

The high biological productivity in the Dome favors the growth of krill populations, a small crustacean of which the blue whale feeds almost exclusively (Fiedler, 2002; Ballance *et al*., 2006; Bailey *et al*., 2009; Fiedler *et al*., 2017). Larger individuals can consume up to 5.5 t of krill per day (Reeves *et al*., 2002). The presence and abundance of blue whales in the Dome has been associated with the high concentrations of krill present in the region (Etnoyer *et al*., 2006; Matteson, 2009), which reach levels of up to 312,000 individuals per m^3, with an average of 13,539 individuals per m^3 (Matteson, 2009).

The presence of newborn blue whales and the abundance of food, confirm that the Dome is a particularly important site for the birthing and feeding of the species (Jiménez, 2016).

During the period 1986-2006, NOAA conducted ten oceanographic cruises in order to estimate the relationship between the distribution of observed blue whales and the environmental variables modeled for the ETP (Fig. 14) (Fiedler *et al*., 2017). One hundred forty-three individuals were sighted with a strong relationship with the Dome, which could belong to the populations of the Northeast Pacific, the Southeast Pacific, or be residents (Sears and Perrin, 2009; Fiedler *et al*., 2017).

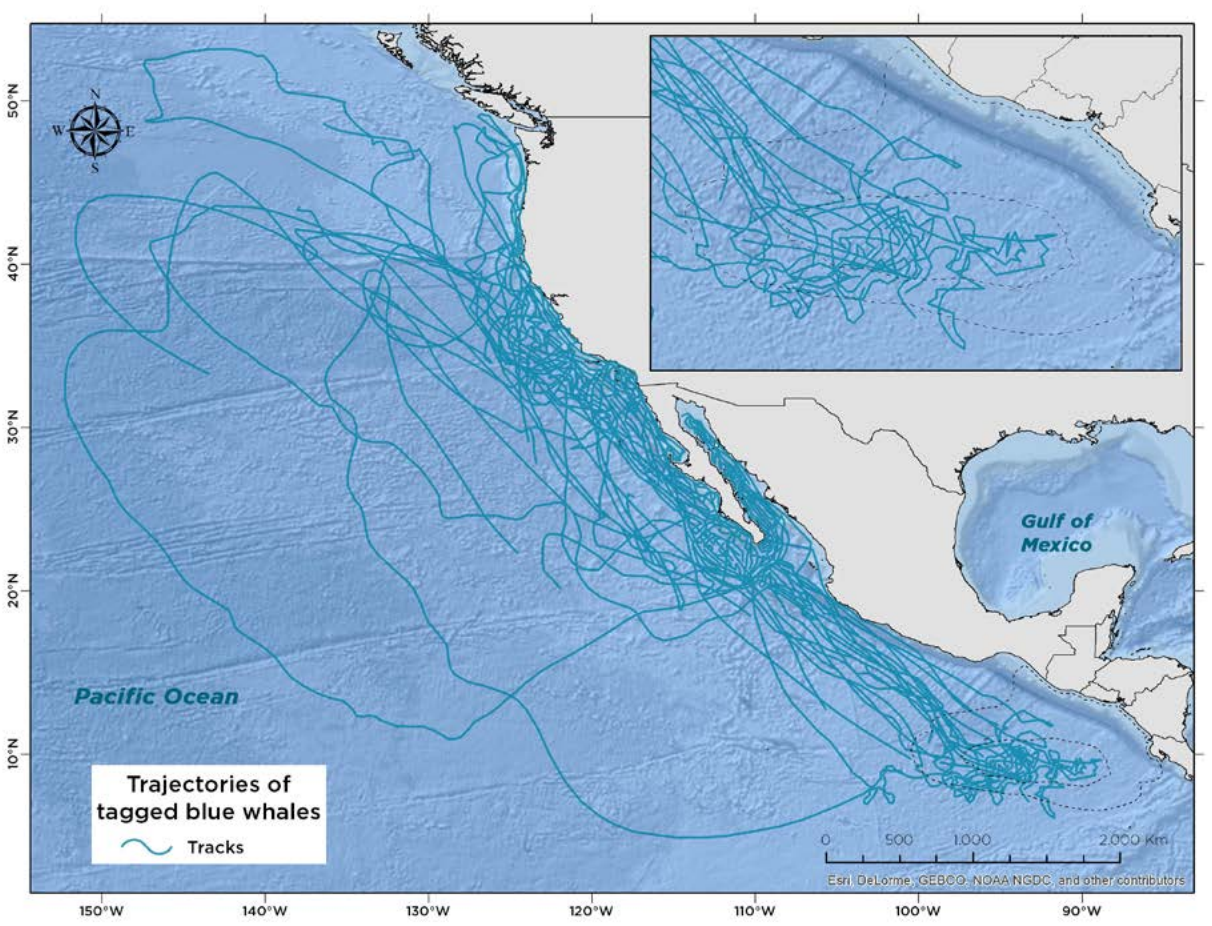


Figure 13. Trajectories taken by 92 blue whales tagged between 1994 and 2007 throughout the Northeast Pacific coast (adapted from Bailey *et al*., 2009).

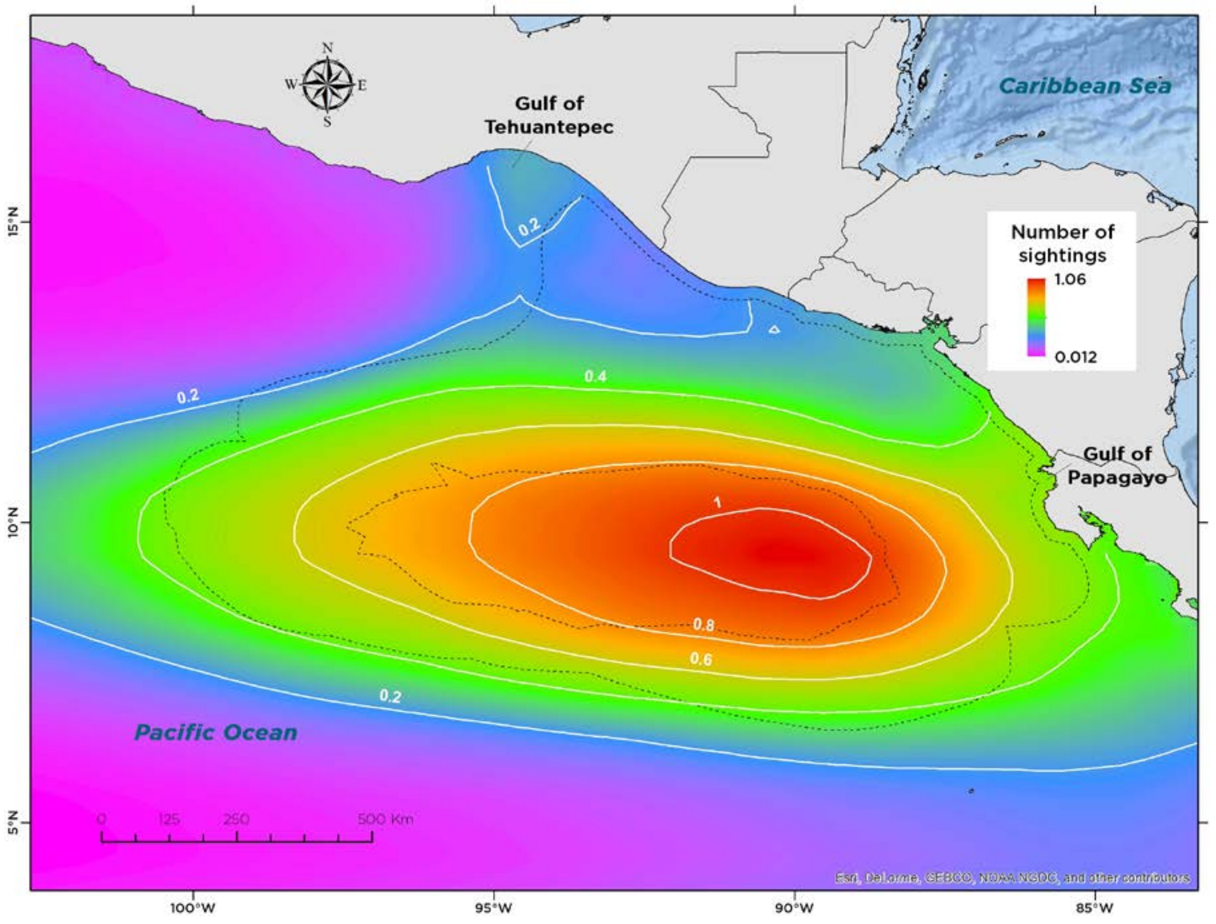


Figure 14. Number of sightings expected for the blue whale in the Dome. The units reflect an index of abundance of the species, generated from the number of registered sightings (per cell of 0.25 x 0.25 degrees or 15 x 15 nm) (adapted from Fiedler *et al*., 2017).

The importance of the Dome for deep water organisms

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Center for Research in Marine Sciences and Limnology.

Despite various studies in the water column, the area under the Dome has been poorly studied. The Middle American Trench, reaching up to 4,600 m in depth, extends through an important section under the Dome.

Beyond the Trench, the abyssal plains can be found; extensive regions of muddy bottoms between 3,000 and 3,500 m in depth, where the darkness is total, and the temperature is around 2˚C. In this region there are some submarine volcanoes. In June 2017 two of them where visited for the first time, thanks to the Deep Submarine Vehicle (DSV) Alvin. The fauna that lives there is surprising, due to the composition of the species, and the great size achieved by some individuals. Octocorals several meters long are observed, as well as glass sponges a meter tall. Is it possible that the high productivity of the Costa Rican Dome, through organic particle precipitations and organisms, is feeding the deep communities, mainly those far from the methane emissaries.

From the Middle American Trench to the coast there is a slope or continental margin. This is a pronounced sloped region, that goes beyond 4,000 m in depth towards the border of the continental platform, around 200 m deep. Off the coast of Guanacaste, in Costa Rica, there are several deep mounds, with the Culebra Mound standing up, at 1,500 m in depth. These mounds have cold methane emissaries, which keep bacterial populations, which serve as food to a great number of organisms. Some ingest the bacteria directly, while others absorb them in their bodies, developing a symbiotic relationship, where the nutrients generated by the bacteria are translocated into the animals.

Since the amount of food shrinks as it gets get further away from the cold methane emissaries, the organic matter supply generated in the Dome can be key to the maintenance of communities in the deepest zones of the region.

Striped dolphin

This species, widely distributed in tropical and warm waters of temperate seas around the world, reaches high concentrations in the Dome (Fig. 15) (Au and Perryman, 1985; Ballance *et al*., 2006; Fiedler *et al*., 2017). They usually form dense herds of 100 animals, but can be counted 500 in a single group (Reeves *et al*., 2002).

The International Union for the Conservation of Nature (IUCN) places it in the category of Minor Concern in its Red List of Threatened Species, with an increasing population trend (UICN, 2012). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) includes it in its Appendix II (CITES, 2009).

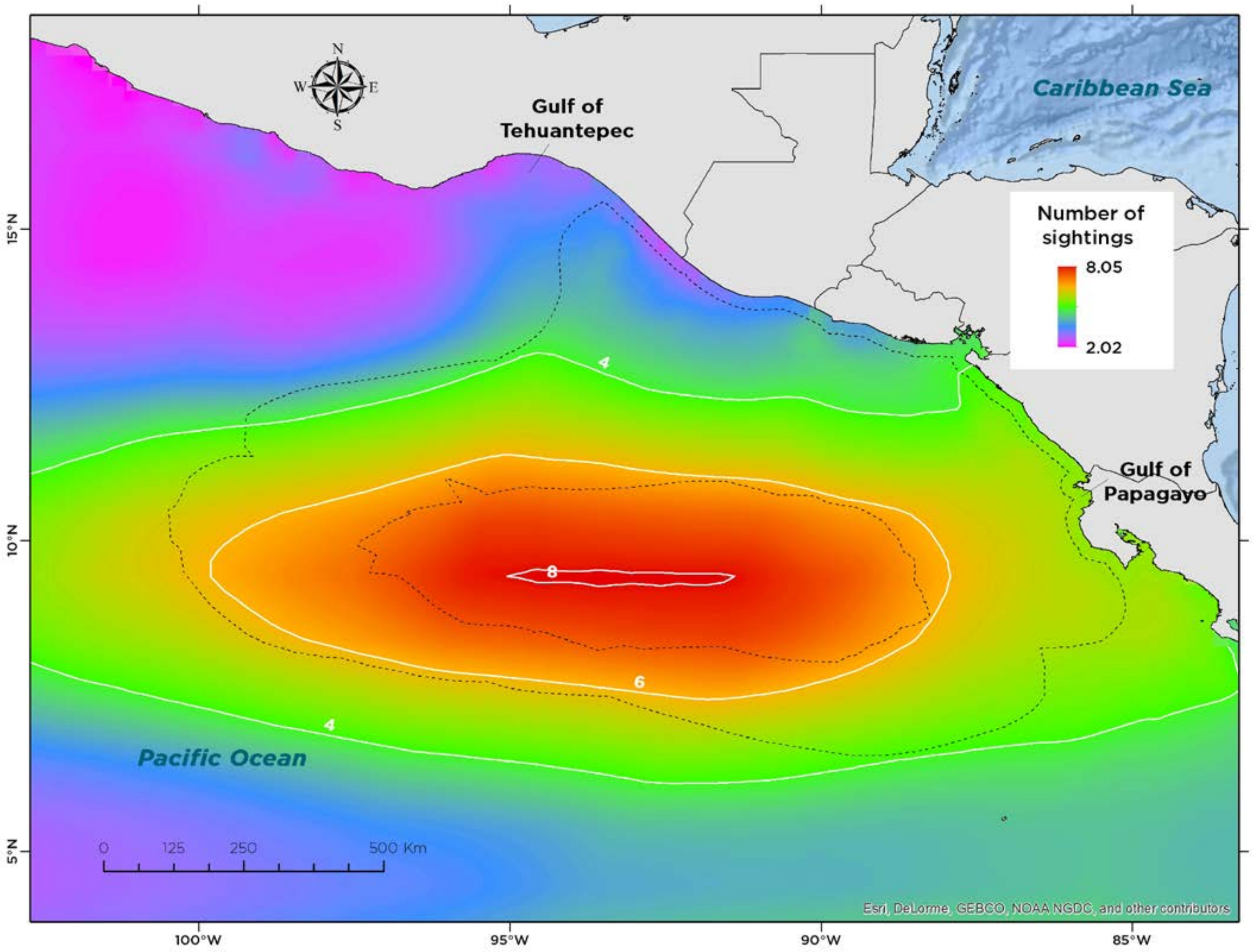


Figure 15. Number of sightings expected for the striped dolphin in the Dome. The units reflect an index of abundance of the species, generated from the number of recorded sightings (per 0.25 cells x 0.25 degrees or 15 x 15 nm) (adapted from Fiedler *et al.,* 2017).

Common dolphin

This species is found in the ETP, from southern California to Chile, with high abundances in the Dome (Fig. 16) (Au and Perryman, 1985; Ballance *et al*., 2006; Fiedler *et al*., 2017).

IUCN places this species in the category of Minor Concern on its Red List of Threatened Species, with an increasing population trend (UICN, 2012). CITES includes it in its Appendix II (CITES, 2009).

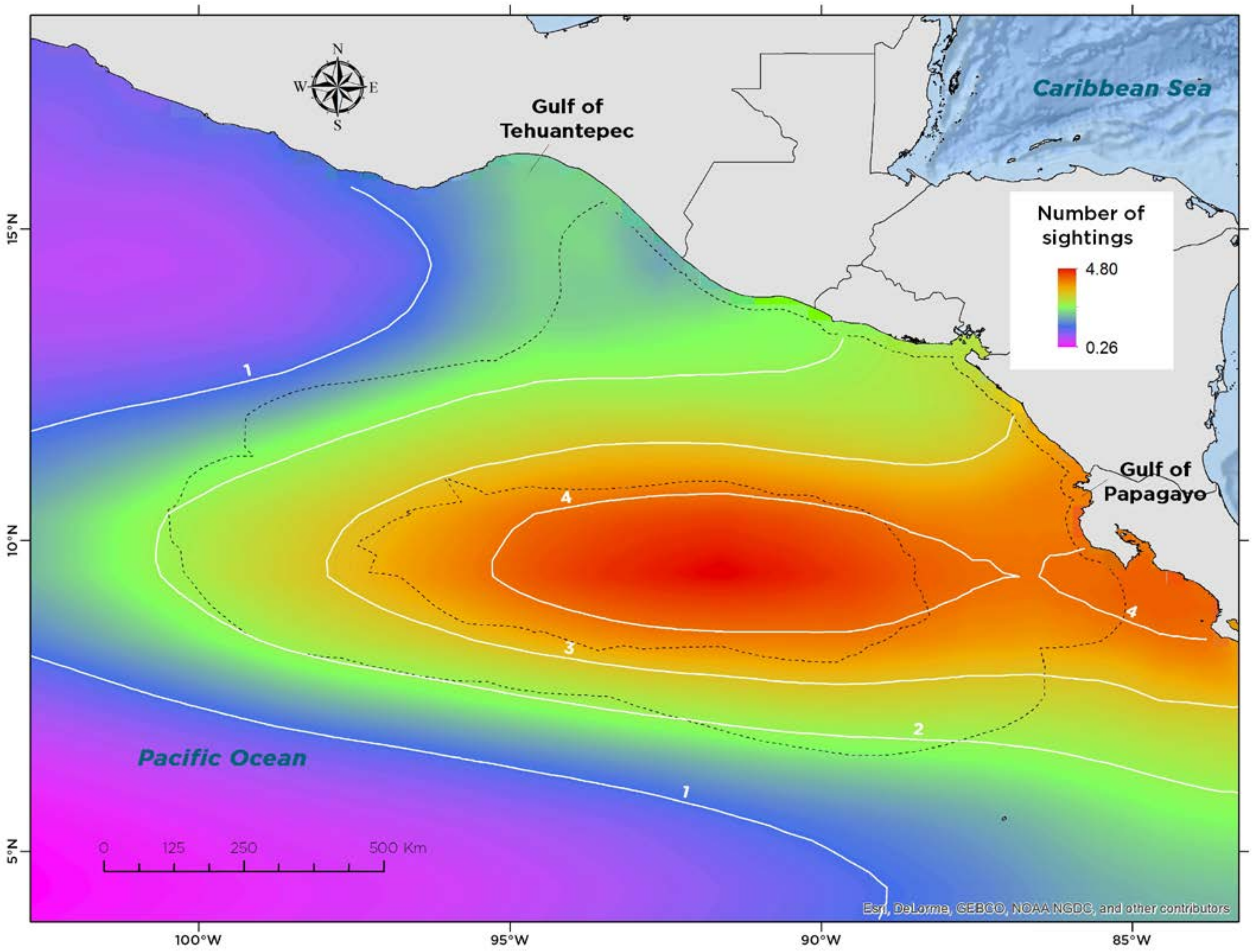


Figure 16. Number of sightings expected for the common dolphin in the Dome. The units reflect an index of abundance of the species, generated from the number of reported sightings (per cell of 0.25 x 0.25 degrees or 15 x 15 nm) (adapted from Fiedler *et al*., 2017).

Spinner dolphin
Stenella longirostris

Economic importance of cetaceans

The whale watching industry contributes significantly to the socioeconomic development of coastal communities (Hoyt and Iñíguez, 2008; Cisneros-Sotomayor *et al.*, 2010).

In Latin America, the sighting of cetaceans generates US $ 79.4 million annually in ticket sales and US $ 278.1 million in total expenses by the more than 880,000 tourists who carry out the activity (Hoyt and Iñíguez, 2008).

At the Central American level (Guatemala, Belize, El Salvador, Honduras, Nicaragua, Costa Rica and Panama), in 2008 it was calculated that there were 145 tour operators dedicated to whale watching, with a total of 188 vessels, distributed in 20 different communities (Fig. 17; Hoyt and Iñíguez, 2008). An update of this information would surely show an increase in activity and the economic impact for coastal communities.

The visitation to carry out this type of tourism entails a significant socioeconomic contribution to the coastal communities. In Central America, several of the species sought by tourists are related to the Dome, as are the bottlenose dolphin (*Tursiops truncatus*), the common dolphin, the pantropical spotted dolphin (*Stenella attenuata*), the spinner dolphin (*Stenella longirostris*) and the short-finned pilot whale (*Globicephala macrorhynchus*)

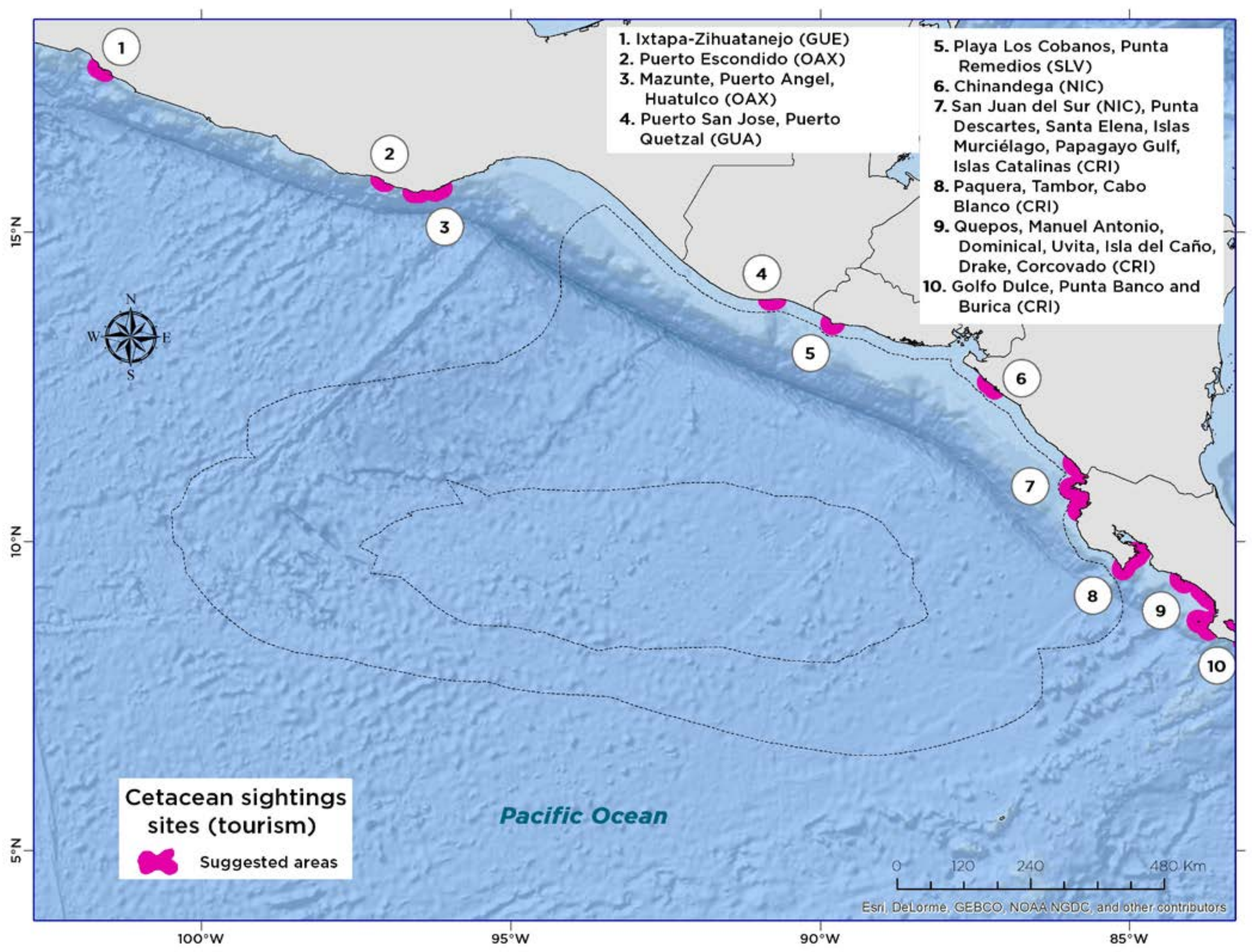


Figure 17. Main cetacean sightings sites (tourism) near the Dome.

Spotted dolphin
Stenella attenuata

Blue Marlin
Makaira nigricans

VI. BILLFISHES

Sailfish (*Istiophorus platypterus*), swordfish (*Xiphias gladius*) and blue marlin (*Makaira nigricans*), black (*Istiompax indica*) and striped (*Kajikia audax*) are members of the group known as billfish or billfishes (Allen and Robertson, 1998). Sailfish and marlin are particularly important for sport fishing, while all species are commercially traded. An important factor observed in the Dome region is the compression of the habitat of pelagic species. The low amount of oxygen in the water column causes these species to concentrate in the first 100 m depth, where concentrations greater than 1 milliliter per liter (ml / l) of dissolved oxygen are found. This makes it easier to catch them by larger species, which in turn support commercial and sport fishing in the region. (CABA, 2015).

Sailfish
Istiophorus platypterus

Sailfish

The sailfish in the Pacific Ocean is a highly migratory species, more abundant in waters near the continents, and rarely penetrates the high seas (Allen and Robertson, 1998; CIAT, 2017; Ross Salazar *et al*., 2017). Their migrations throughout the American continent respond to seasonal changes in water temperature, often found in waters with temperatures above 28˚C. The species spawns off the Mexican coast during summer and autumn, and off Costa Rica in the winter (CIAT, 2017).

Sailfish prefer areas with strong gradients of temperature, salinity, oxygen and nutrients, such as those that occur in the periphery of the Dome, where there are greater feeding opportunities for both adults and larvae (Vinogradov *et al*., 1991; Franks, 1992; Evseenko and Shtaut, 2005; Woodson and McManus, 2007; Braun *et al*., 2015). This species avoids regions with a shallow thermocline and low concentration of dissolved oxygen, so it stays away from the center of the Dome. Those sailfish that cross the Dome do so at high speed and without changing direction (Fig. 19; CABA, 2015).

Satellite tracking of sailfish tagged in Costa Rica showed that, in December, they are heading slightly south-southeast, while those tagged in March remained in the area and then migrated to north-northwest (Fig. 19; CABA, 2015; Ehrhardt, 2017)

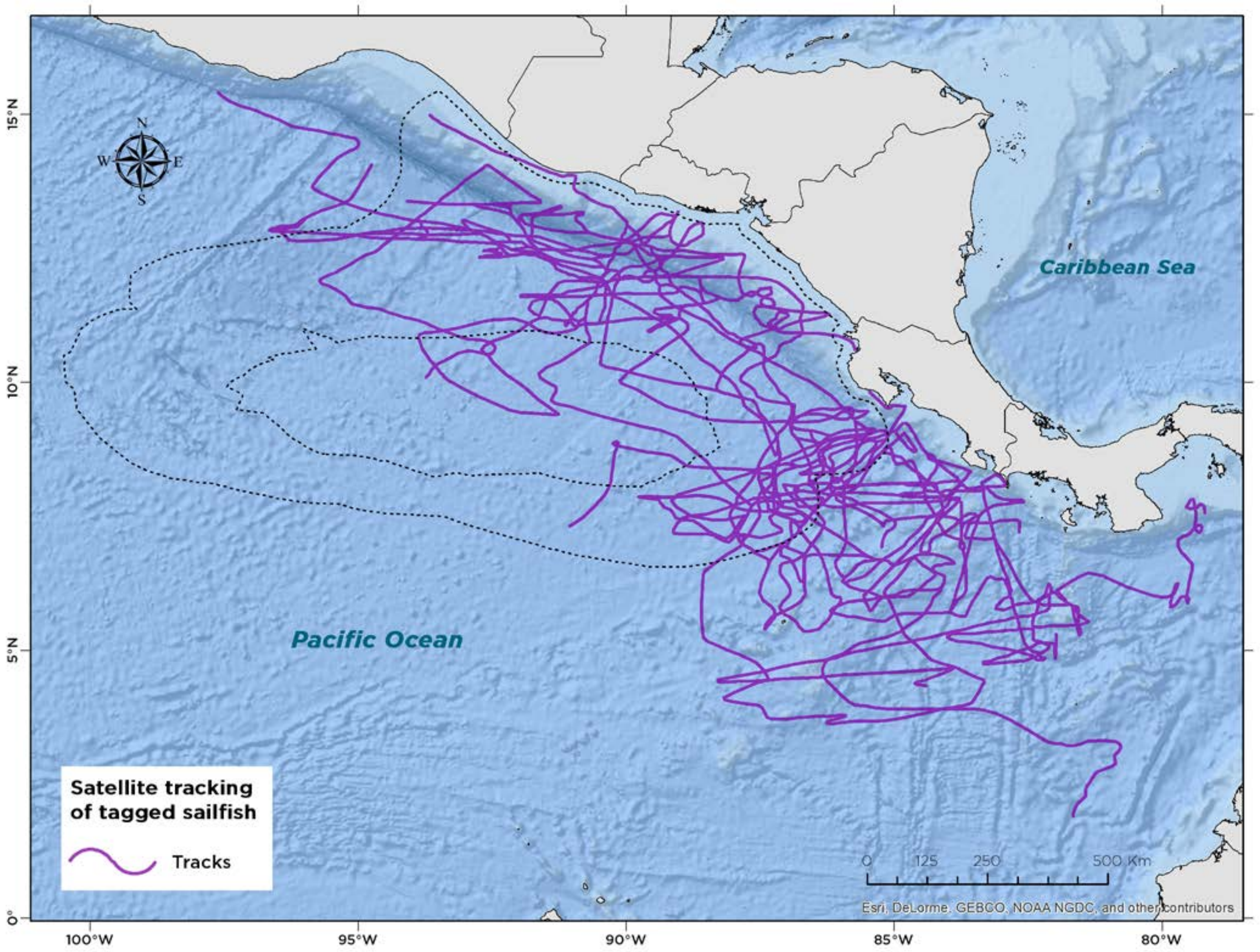


Figure 18. Satellite tracking of tagged sailfish in the Pacific Coast of Central America (adapted from CABA, 2015; Ehrhardt, 2017).

Sailfish commercial fishing

The main fleets that catch sailfish in the ETP are long liners, mainly from Taiwan, Japan, China and Korea. It is also captured by longline fleets with smaller vessels, particularly those operating in the Central American coastal waters; and the artisanal and recreational fisheries of Central and South America; occasionally they are caught in purse-seine fisheries (CIAT, 2017).

Sailfish catches showed a decreasing trend during the period 1994-2009; and since then it has remained constant at this level or slightly descendant. Annually, catches of 500 t are reported for the region, considerably less than the 1993-2007 average of 2,100 t. Due to this decreasing trend, the IATTC recommended a precautionary approach in the fisheries management of the species (CIAT, 2017).

The decline is also seen in sailfish catches in sport fisheries, which affects local economies. This decline is attributed to: i) an excess of incidental catches in the longlines used only for fishing dolphinfish, tuna and shark from the fleets of Costa Rica, Ecuador, Panama, Peru and Taiwan; ii) a significant development of coastal artisanal fisheries in Costa Rica and, to a lesser extent, in Nicaragua, Guatemala and Panama, which capture sailfish and iii) migrations to the open sea during some seasons of the year, carried out by the species. The decline of this population reflects the lack of vision in the use of this valuable resource that represents sustainable fishing development opportunities at the coasts (Ehrhardt and Fitchett, 2008).

Sailfish
Istiophorus platypterus

Sports fishing for billfish

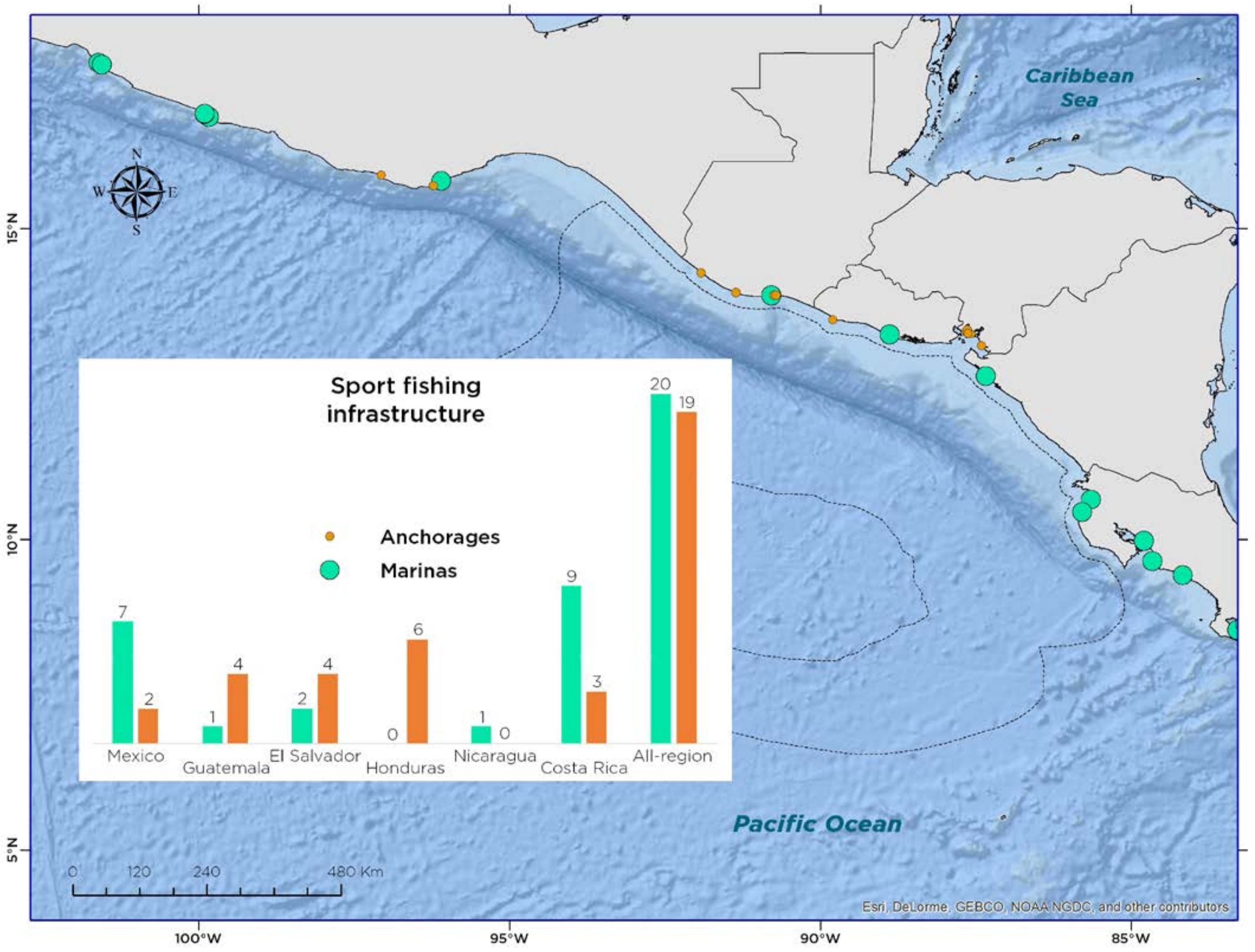
Sport fishing is a growing industry in the region, providing work options to coastal communities (Fig. 19). The marlin and the sailfish are the main attraction for the practitioners of this activity (Ditton and Grimes, 1995; Holland *et al*., 1998). In Guatemala it is estimated that sport fishing generates income of US $ 25 million per year (Villagrán, 2015). In Costa Rica, the University of Costa Rica calculated the contribution of sport fishing to the national economy in US $ 599 million per year (Yong-Chacón *et al*., 2010). While in Panama, sports fishermen contribute US $ 170.4 million annually to the local economy (Southwick *et al*., 2013).

In Costa Rica, the US $ 599 million generated by sport fishing in 2008 represented 2.13% of the Gross Domestic Product (GDP), with US $ 279 million in the investment category and US $ 77.8 million in fiscal charges. The industry contributed 63,000 jobs, mostly in coastal areas. Of the total of 438 hotels and companies devoted to tourism in coastal areas, 239 offered some type of sport fishing service. It was estimated that, in 2009, 22% of visitors to Costa Rica did so to practice sport fishing, totaling 283,790 tourists (Yong-Chacón *et al*., 2010).

In Panama, in 2011, 86,000 tourists who practiced sport fishing in the country were reported, of those, 22,000 arrived exclusively to practice this activity. For that year, sport fishing generated 9,503 jobs, represented US$3.1 million in taxes and an increase of US $48.4 million to GDP (Southwick *et al*., 2013).

Central America has become a world destination for sport fishing, due to two main factors: i) high rates of billfish capture due to the population densities of this group in the region and ii) the high availability of trophy sizes (Ehrhardt and Fitchett, 2008). However, a decline in the abundance of the sailfish of 82% is reported, after having established the fishing regime of high-altitude industrial long liners in the region. For 2008, longline long liners placed 150 million hooks in the ETP (Ehrhardt and Fitchett, 2008). Under this fishing pressure, the size of trophy specimens of sailfish has been reduced by 46% of the original levels (Ehrhardt and Fitchett, 2008).

Central America has tried to manage the development of sport fishing as a growth option for the coastal areas of the region. In 2009, a Regional Action Plan was promoted to Unify Criteria for Sustainable Management of Billfishes and Sport Fishing (OSPESCA and TBF, 2009). Unfortunately, most of the proposed actions have not been implemented.



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

Figure 19. Main sport fishing marina close to the Dome.

Central America world destination for sport fishing

VII. SHARK AND RAYS

Sharks and rays are another group of commercially relevant species associated to the Dome. The biological characteristics of these species they make them especially susceptible to overfishing; they grow slowly, have late sexual maturity and have few offspring (Clarke *et al.*, 2006; Kohin *et al.*, 2006; Clarke *et al.*, 2007; Morgan, 2010; White *et al.*, 2012).

Giant manta
Mobula birostris

Sharks are caught mainly for their fins and their flesh (Morgan, 2010). It is estimated that up to 73 million sharks are caught annually to meet the demand for shark fin (Clarke *et al*., 2006). This exploitation has generated reports of declining populations by 70-80% around the world (Morgan, 2010).

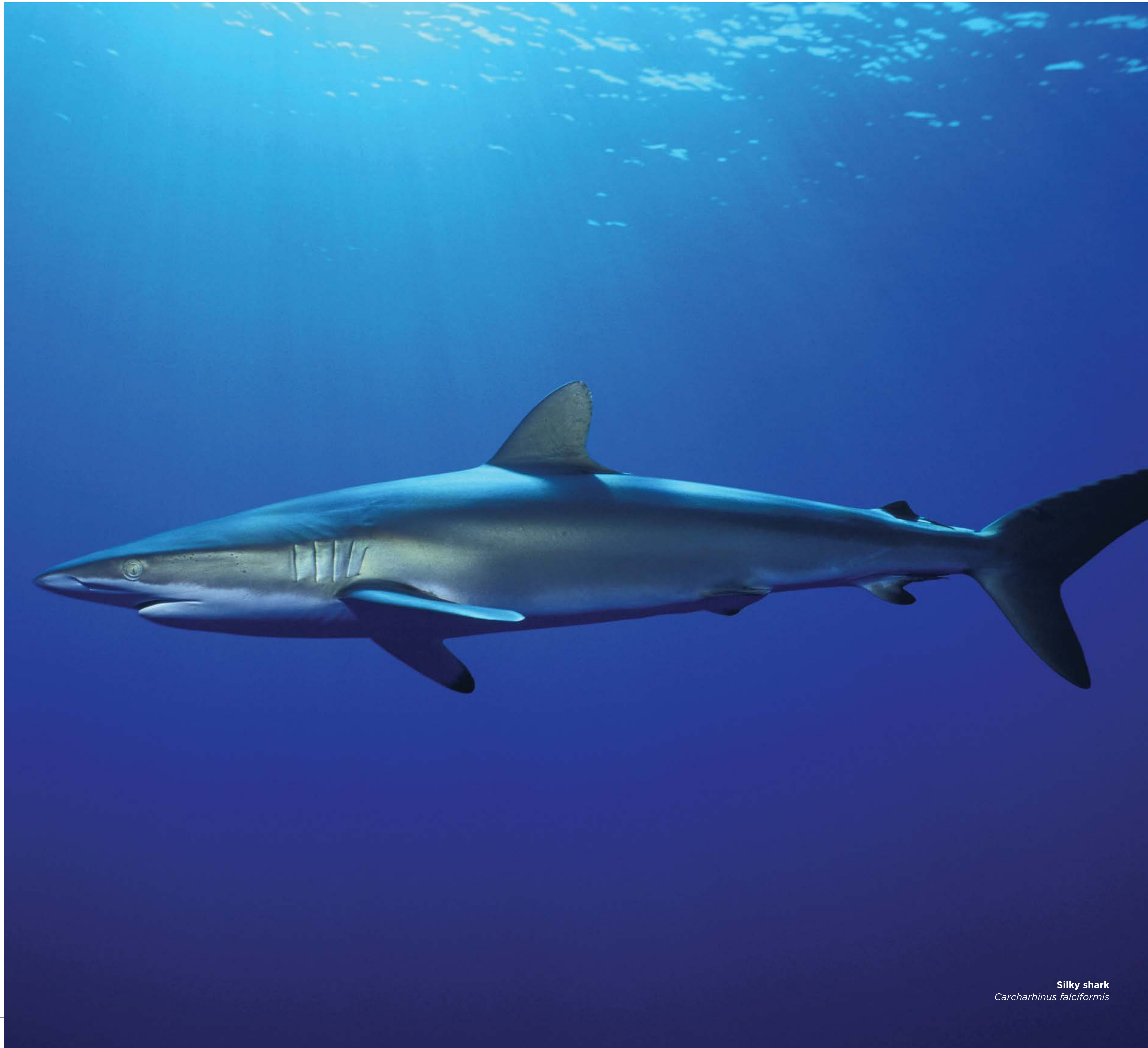
The shark species most commonly caught in longline fisheries in the Dome area are the thresher shark (*Alopias vulpinus*), the blue shark (*Prionace glauca*), the silky shark (*Carcharhinus falciformis*) and the common hammerhead shark (*Sphyrna lewini*) (Brenes *et al*., 2000). This agrees with scientific studies in the area that made evident an important presence of silky shark and thresher shark (Kohin *et al*., 2006; Johnson *et al*., 2018). These species are distributed over the 15˚C thermocline (Brenes *et al*., 2000).

The satellite tracking of sharks has allowed confirmation that they travel along the Central American and Mexican coast, as well as between the coastal areas and the Dome, establishing an ecological connectivity in the region. A marked silky shark moved 2,500 km to the entrance of the Gulf of California and then returned to the Dome area during a 10 month period (Fig. 20; Kohin *et al*., 2006).

Silky shark

The silky shark can reach up to 3.5 meters and weigh 346 kilograms (kg). It inhabits tropical waters around the world, where it is a dominant species in fisheries, either as a target species or as bycatch (Froese and Pauly, 2012; Ross Salazar *et al*., 2017). It is important to consider that this is the most commonly caught shark species in the region (Arauz *et al*., 2007; Arauz *et al*., 2008; CIAT, 2017), probably because it inhabits 99% of its time in surface waters (Arauz *et al*., 2008). His size of sexual maturity has been estimated at 2.28 m (Froese and Pauly, 2012). However, most of the silky sharks caught are juveniles (Arauz *et al*., 2008).

The silky shark, due to the decline of its populations, is considered vulnerable in the IUCN Red List (IUCN, 2018). This shark species is one of the most captured in the ETP, which is why it recorded a 32% reduction between 1994 and 2015 in the region. (Lennert-Cody *et al*., 2016). This decline led to its inclusion in Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) in 2014 and Appendix II of CITES in 2016



Silky shark
Carcharhinus falciformis

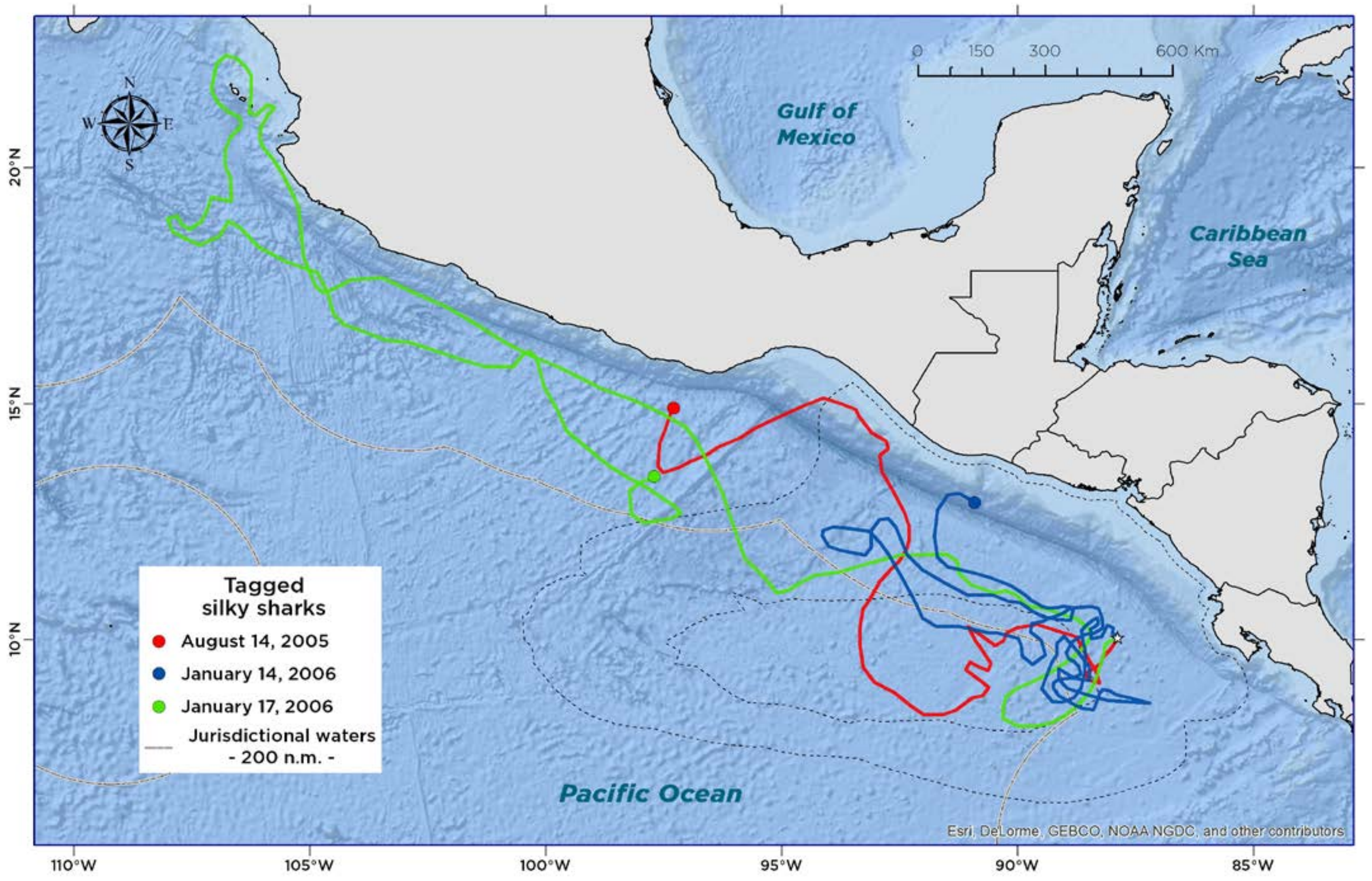


Figure 20. Marked shark movements in the Dome region (adapted from Kohin *et al*., 2006).

Tourism with sharks

Globally, the economic impact of ecological tourism focused on shark observation represents an industry greater than US $314 million / year, contributed by 590,000 tourists, generating 10,000 jobs (Cisneros-Montemayor *et al*., 2013). It is estimated that the number of people observing sharks could double within the next 20 years, generating more than US$780 million annually (Cisneros-Montemayor *et al.*, 2013).

This contrasts with the estimated value of US$630 million per year for shark fisheries, which have been declining for more than a decade (Cisneros-Montemayor *et al*., 2013).

In 2011, Honduras turned its seas into the first shark sanctuary in the Americas, declaring its EEZ of 240,000 km^2 a Bioceanic Shark Sanctuary.. This initiative seeks to protect species such as the hammerhead, bull, nurse, tiger and gray sharks, as well as promoting the management of sites such as the Gulf of Fonseca, considered a hammerhead shark breeding area (La Razón, 2012).

In Costa Rica, the shark and ray fisheries represented in 2006 an income of US$236,000 for the local economy, whereas a common hammerhead shark linked to the tourist activities of a country represents a value of more than US$82,000 per year. Thus, just one common hammerhead shark to visit Isla del Coco every year for twenty years, could generate US$1.6 million during its lifetime (Friedlander *et al*., 2012).

The fishing of sharks and rays in the region of the Costa Rica Thermal Dome

Randall Arauz,
Fins Attached

Sharks

The upwelling of deep waters in the Thermal Dome zone attracts important populations of commercial interest fish, among them the yellow fin tuna (*Thunnus albacares*), the dolphinfish (*Coryphaena hippurus*), marlin (Istiophoridae) and the sharks (Sphyrnidae, Carcharhinidae, Alopidae), which are captured by purse-seine and longline fisheries.

Between 1999 and 2008 observations were made aboard the longline fleet of Playas del Coco, Guanacaste, Costa Rica. Two-hundred seventeen commercial hauls were analyzed, each haul with an average length of 20 km (with 600 to 800 circular hooks, #14). Common dolphinfish was the most captured species (53.14 ± 72.58 individuals per 1,000 hooks). Several species of sea turtles and sharks included in the lists of endangered species of IUCN were also captured, like the ridley sea turtle (*Lepidochelys olivacea*; vulnerable; 9.05 ± 10.11 individuals per 1,000 hooks), the silky shark (*Carcharhinus falciformis*; vulnerable; 2.96 ± 5.56 individuals per 1,000 hooks), the green turtle (*Chelonia mydas*; endangered; 0.35 ± 0.81 individuals per 1,000 hooks), small amounts of common hammerhead shark (*Sphyrna lewini*; endangered; 0.041 ± 0.279 individuals per 1,000 hooks), the oceanic whitetip shark (*Carcharhinus longimanus*; vulnerable; 0.037 ± 0.247 individuals per 1,000 hooks) and the hammerhead shark (*Sphyrna zygaena*; vulnerable; 0.025 ± 0.217 individuals per 1,000 hooks). Besides, the capture of the pelagic ray was very common (*Pteroplatytrygon violacea*; 4.77 ± 6.10 individuals per 1,000 hooks), the elasmobranch being the most commonly reported in the captures.

Dolphinfish is a highly seasonal resource; whose abundance varies between 3 individuals per 1,000 hooks up to 122 individuals per 1,000 hooks. Its biggest catch occurs between October and February, with a peak between December and January. The capture of the silky shark is also seasonal, varying between 0,86 individuals per 1,000 hooks and 2.6 individuals per 1,000 hooks. In contrast with the dolphinfish's, its biggest catch happens between July and November, with a peak between September and October. The capture of the ridley sea turtle is also seasonal, varying between 3 individuals per 1,000 hooks and 22 individuals per 1,000 hooks, coinciding with the seasonal pattern exhibited by the silky shark capture.

Generalized Linear Models (GLM) developed from the capture rates showed a reduction for these during the 10 years of this study. The catch of dolphinfish went from 50 individuals per 1,000 hooks in 1999 to 16 individuals per 1,000 hooks in 2008; and the capture of the silky shark went from 4.7 individuals per 1,000 hooks in 1999 to 0.9 individuals per 1,000 hooks in 2008. In contrast, an increase in the capture of ridley sea turtles, of 2 individuals per 1,000 hooks in 1999 to 39 individuals per 1,000 hooks in 2008. The average size of dolphinfish has also been reduced, with 95% of the individuals captured in 2008 not reaching their minimum maturity size.

Silky shark
Carcharhinus falciformis

A closure of the longline fishery between July and September (when the lowest dolphinfish captures happen, and the highest sharks and turtles capture) could mitigate the impact of bycatch over these threatened species, while maintaining the productivity of the fishery.

Studies using modified baits and circle hooks showed that these do not manage to reduce the capture of turtles, although they do report a higher capture of sharks. What we are facing here, is a problem of overfishing with ecosystem implications. Monospecific solutions will not work.

More sharks swell the lists of endangered species year after year and enjoy greater protection in international forums. Despite this, the fishing effort continues on them interruptedly. To provide the protection they need, a serious reduction of the fishing effort is necessary, though seasonal closures to longline fishing on a regional scale, or through seasonal closures in identified biological corridors and adult aggregation sites.

Rays

Mantas and rays share the same biological characteristics of sharks, which makes them especially susceptible to overfishing (White *et al*., 2012; Dulvy *et al*., 2014). Of pelagic elasmobranch species, mantas and mobulas are among the most vulnerable (Croll *et al*., 2016).

Both the mobulas and the giant mantas are frequently observed in the Dome, evidenced by their incidental capture in purse seines for the capture of yellowfin tuna. The species most commonly captured in this region in purse seines are the giant manta (*Mobula birostris*) and possibly the Alfred manta (*Mobula alfredi*), the devil mobula or Munk (*Mobula munkiana*), the smoothtail mobula (*Mobula japanica*), the Chilean devil ray (*Mobula tarapacana*) and the smoothtail mobula (*Mobula thurstoni*) (Hall and Roman, 2013). The pelagic stingray (*Pteroplatytrygon violacea*) is also frequently captured in the Dome (Hall and Roman, 2013). This species generally makes seasonal migrations to warm waters to reproduce, returning to higher latitudes to have their offspring (Hall and Roman, 2013).

Smoothtail mobula
Mobula thurstoni

Tourism with rays

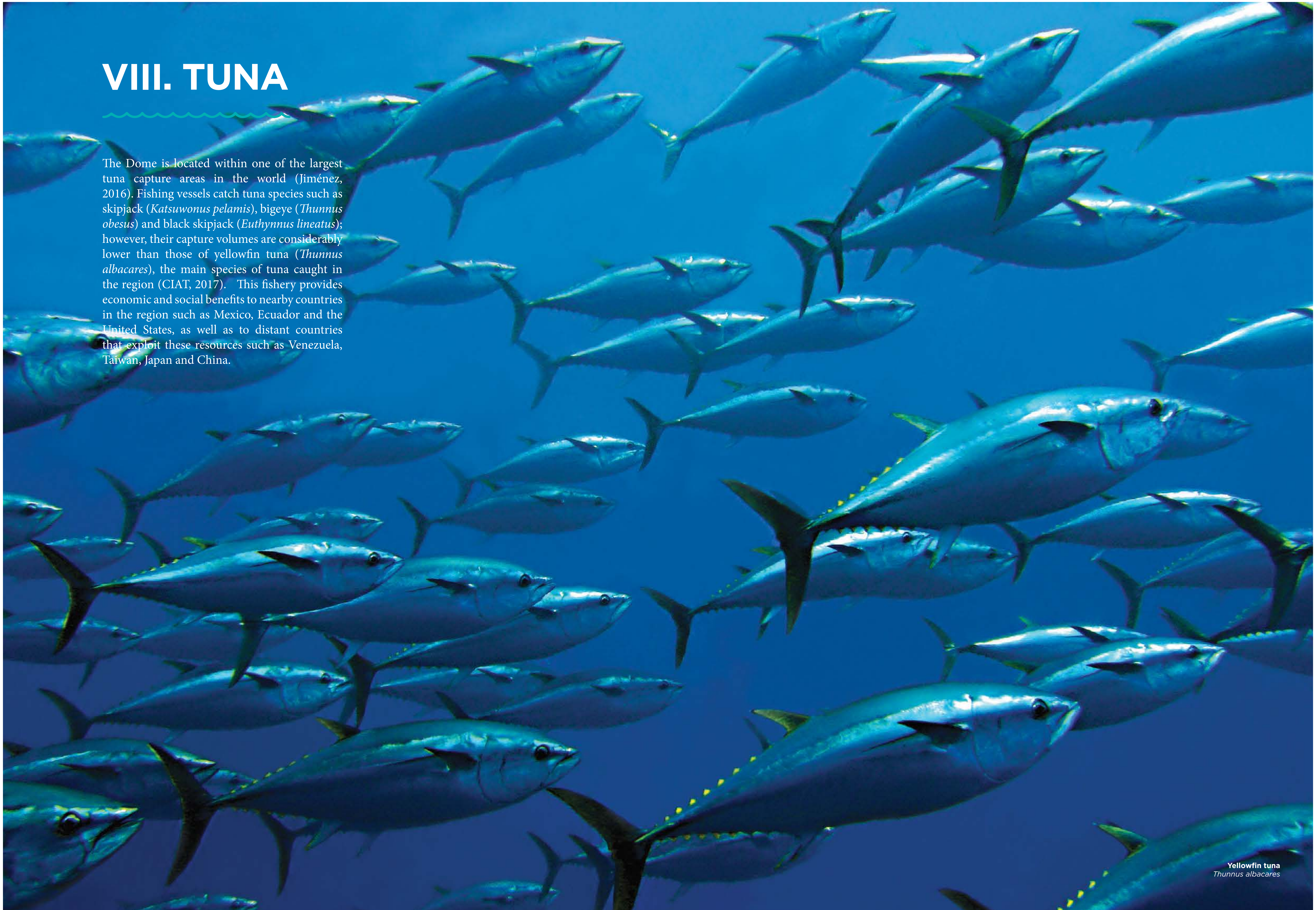
Tourism for manta ray sightings is significant. Overall, this tourism has a direct annual impact of US$73 million and US$140 million per year, if indirect costs are included. (O'Malley *et al.*, 2013).

In Costa Rica, local tour operators promote two dive sites specifically for the sighting of manta rays, with a total of 2,184 dives per year to observe them, spending US$109,200 (O'Malley *et al*., 2013).

This is an activity with high growth potential if promoted properly in Central America. Manta rays are highly migratory species that visit the EEZs of the Central American countries and have an important relationship between the coast and the Dome.

VIII. TUNA

The Dome is located within one of the largest tuna capture areas in the world (Jiménez, 2016). Fishing vessels catch tuna species such as skipjack (*Katsuwonus pelamis*), bigeye (*Thunnus obesus*) and black skipjack (*Euthynnus lineatus*); however, their capture volumes are considerably lower than those of yellowfin tuna (*Thunnus albacares*), the main species of tuna caught in the region (CIAT, 2017). This fishery provides economic and social benefits to nearby countries in the region such as Mexico, Ecuador and the United States, as well as to distant countries that exploit these resources such as Venezuela, Taiwan, Japan and China.



Yellowfin tuna
Thunnus albacares

Yellowfin tuna

The oceanographic characteristics of the Dome and its surrounding areas make it one of the four areas with the greatest potential for finding yellowfin tuna in the ETP (Fig. 21). Within a 300-mile radius around the Dome, captures of yellowfin tuna ranged from 26 t / day to 2.5 t / day between 1976-1988. During years where El Niño occurs, catches fall (2.5 t / day), although fisheries recover quickly in a few months (to 13.5 t/ day; De Anda- Montañez *et al*., 2004).

The fishery for yellowfin tuna has generated, for decades, the installation of important tuna canning companies in Mexico, El Salvador and Costa Rica.

The Central American countries and Mexico have important captures of yellowfin tuna in the ETP. In 2015, Mexico captured the largest volume with 106.188 t (43% of the total captured in purse seine networks in the ETP), followed by Panama with 26.574 t (11% of the total captured in purse seines in the ETP) and Nicaragua with 6.878 t (3% of the total captured in purse seines in ETP) (CIAT, 2017; Bayliff and Majkowski, 2007).

Regarding captures of yellowfin tuna by longline vessels from the Central American countries and Mexico, the captures were led by Costa Rica with 1,415 t (14% of longline catches in the ETP). The captures in the rest of the countries were minimal (CIAT, 2017).

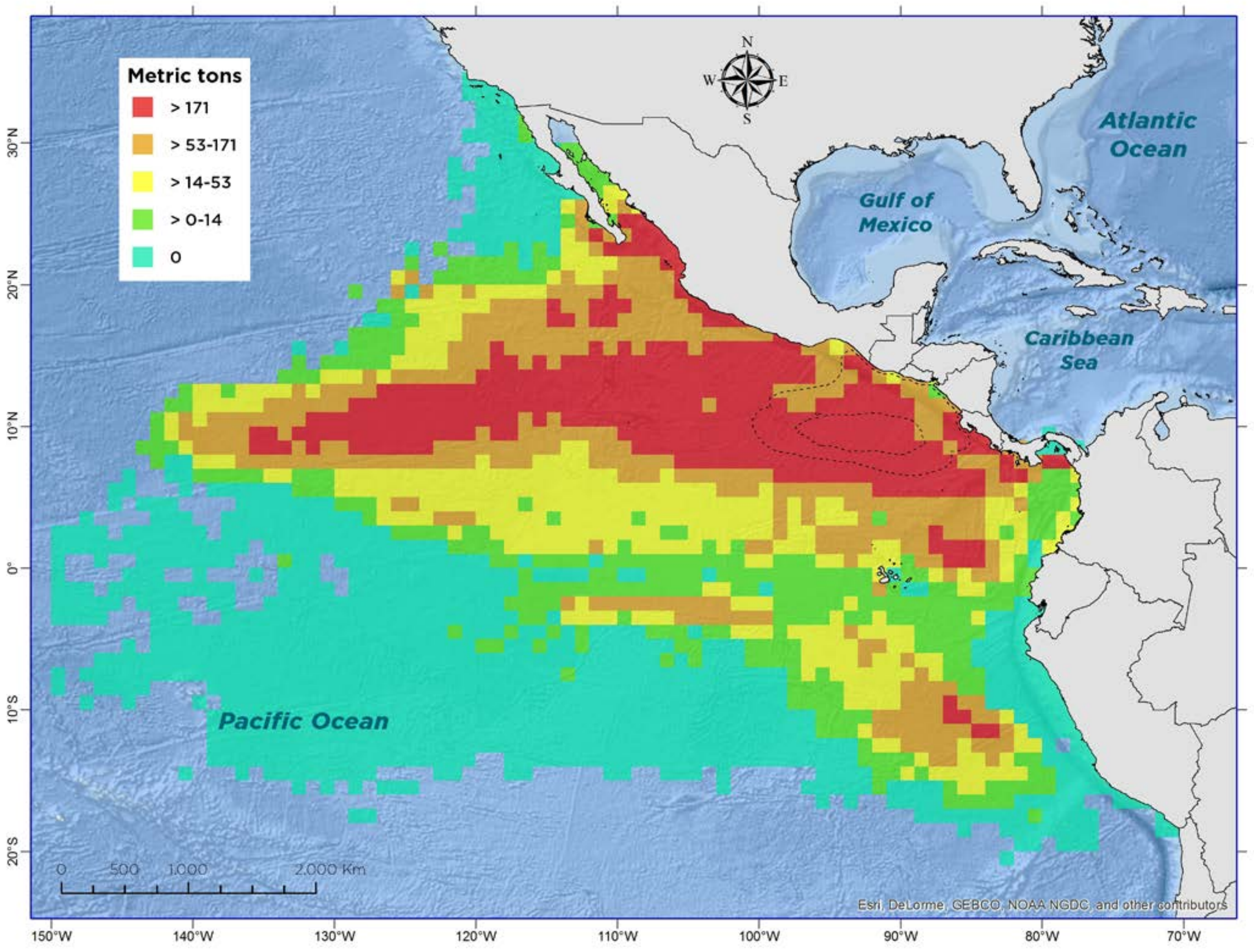


Figure 21. Average catch of yellowfin tuna for the 1985-1999 period (adapted from the IATTC database).

Yellowfin tuna
Thunnus albacares

IX. MARINE TURTLES

Sea turtles are migratory species that make extensive movements between their feeding habitats, breeding areas and nesting beaches. This group exemplifies the connectivity between coastal zones and oceanic zones.

The Dome is of particular interest for the species of marine turtles in the region. Some species, such as the olive ridley turtle (*Lepidochelys olivacea*), show a high permanence in the area (Swimmer *et al*., 2009; Johnson *et al*., 2018). And the leatherback turtle (*Dermochelys coriacea*), uses the Dome as a transit site on its route to feeding areas and as a growth zone for neonates (Shillinger *et al*., 2008; Shillinger *et al*., 2012). Despite its economic relevance (especially in tourism), the incidental capture of sea turtles in fishing lines is worrisome (Swimmer *et al*., 2006). In the ETP it is estimated that 19.3 turtles are captured per 1,000 hooks in longline fisheries (Wallace *et al*., 2010a; Wallace *et al*., 2010b).

Green turtle
Chelonia mydas

Leatherback turtle

The leatherback turtle is classified as Vulnerable worldwide (UICN, 2012). However, during the last three generations, the population of the Eastern Pacific has been reduced by more than 97%, going from more than 35,000 nests per year to less than 1,000 nests per year in the region (Eckert, 1993; Santidrián Tomillo *et al*., 2007; Sarti Martínez *et al*., 2007). These significant reductions are attributed to the extensive collection of eggs for human consumption and incidental mortality in fishing gear. (Eckert, 1993; Shillinger *et al*., 2008; Wallace and Saba, 2009; Tapilatu *et al*., 2013).

Despite continued research and conservation efforts of leatherback turtles on nesting beaches, little is known about their use of oceanic habitat and migratory routes (Shillinger *et al*., 2008; Shillinger *et al*., 2012). The satellite tagging of 46 females in Playa Grande, Costa Rica, during the 2004-2007 period, allowed analyzing 12,095 cumulative days of satellite tracking and identifying their migratory pattern (Fig. 22) (Shillinger *et al*., 2008).

After spawning in the Pacific coast of Mesoamerica, leatherback turtle females head towards the Southern Hemisphere, crossing the Dome, using fast and directed movements (Shillinger *et al*., 2008).

Leatherback turtle
Dermochelys coriacea

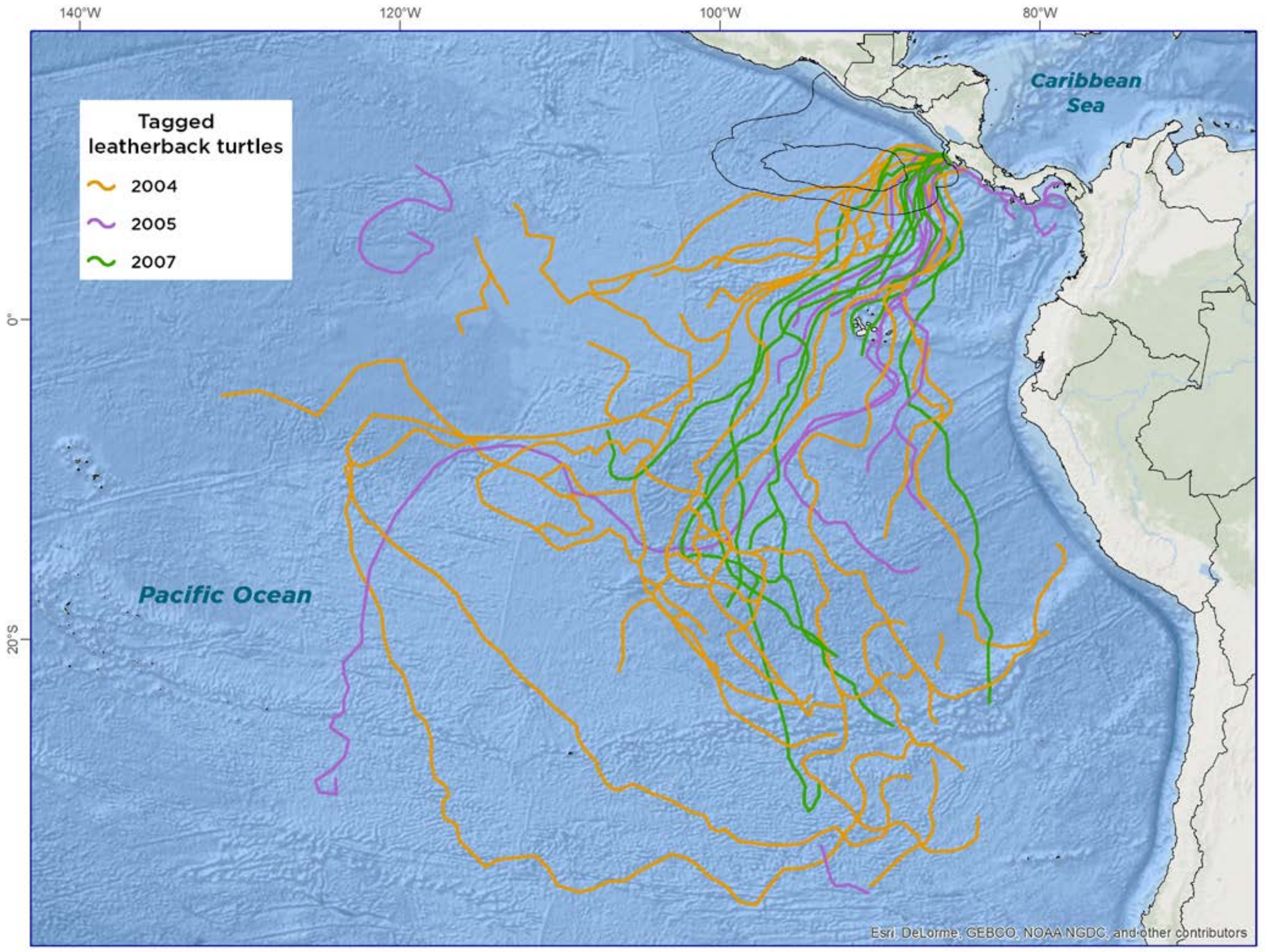


Figure 22. Movements of 46 tagged leatherback turtles in Playa Grande, Costa Rica (adapted from Shillinger *et al*., 2008).

In the case of neonates, studies on four Mesoamerican beaches (Barra de la Cruz, Mexico, Playa Chacocente, Nicaragua, and Playa Grande and Playa Carate, Costa Rica) have identified that they disperse under a significant influence of coastal currents and ocean swirls, keeping them off the Central American coasts in the area of the Dome (Shillinger *et al*., 2012).

Ridley turtle

Adults of ridley or loggerhead turtles are observed closer to the coast than in the open sea. And they prefer to nest more in continental beaches, than in oceanic or continental islands (Rueda Almonacid *et al*., 2005). The species is classified as Vulnerable with a decreasing population trend, since between the seventies and the beginning of this century, the reduction of its populations was estimated between 31 and 36% (UICN, 2012).

The Dome is an area of aggregation of this species, using it intensely (Fig. 23). In 2017, two ridley turtles that were collected and marked in the Dome, showed a high correlation with the area during the following four months, staying inside and in waters near the Dome (Johnson *et al*., 2018). While 14 ridley turtles marked nearby in the Gulf of Papagayo, between November 2001 and June 2003, also showed high persistence in the Dome (Swimmer *et al*., 2009).

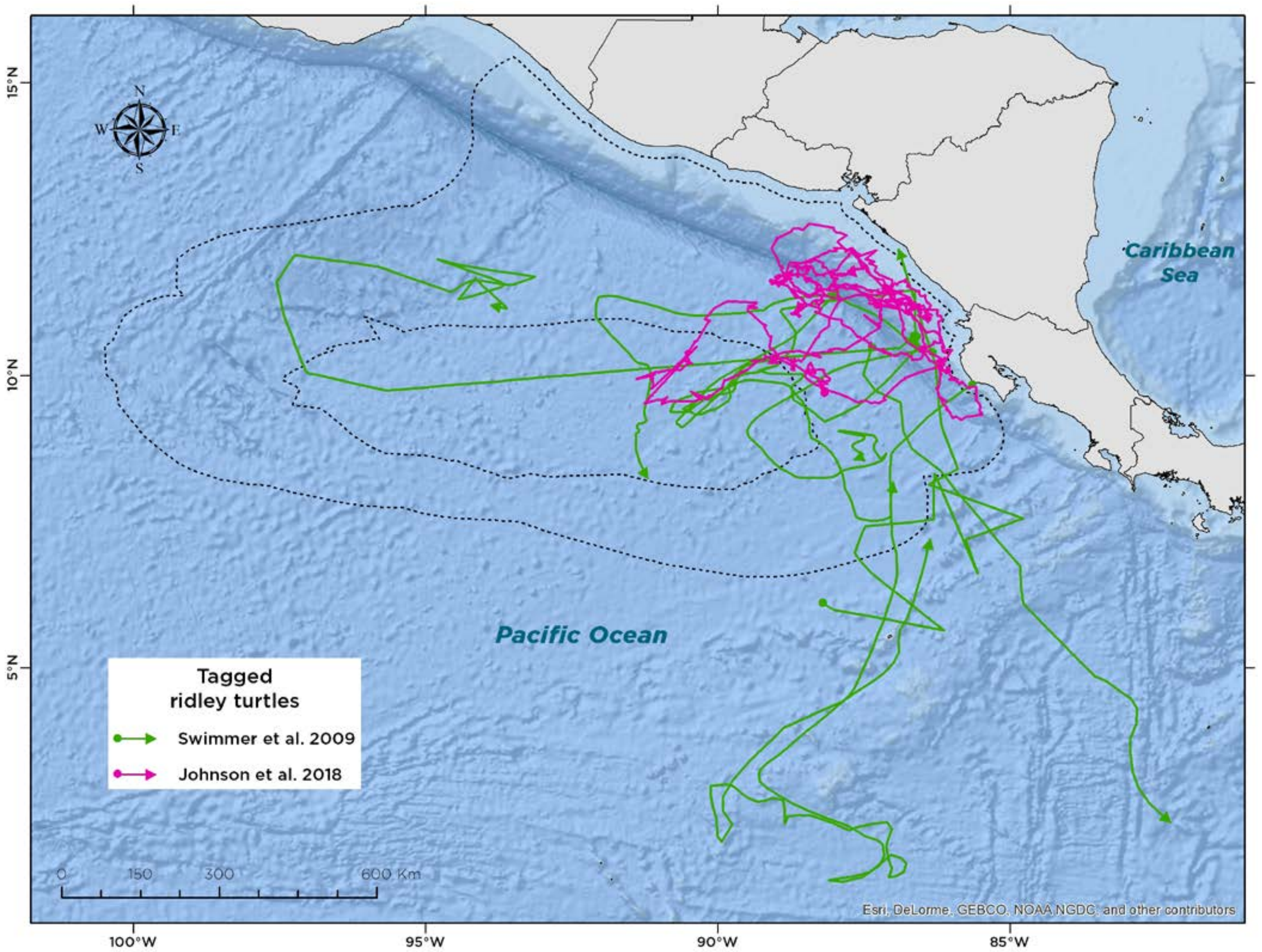


Figure 23. Movements of ridley turtles tagged on the Dome (Swimmer *et al*., 2009; Johnson *et al*., 2018).

Ridley turtle
Lepidochelys olivacea

The environmental, economic and social importance of nesting beaches in local communities

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In the Central American Pacific, no less than 213 important sea turtle nesting beaches are reported (FFI and MARENA, 2007; MARN, 2014; Muccio and Pérez, 2015; MiAMBIENTE, 2017; SINAC, 2017). In the majority of these places, protection, conservation, environmental education, scientific research, ecological monitoring and tourism activities are developed.

The annual gross income from tourism related to the observation of leatherback turtle spawning at Las Baulas Marine National Park (PNMB), Costa Rica, fluctuated, for the period 1993-2002, between US$900,460 and US$1,121.05 per year (Gutic, 1994; Troëng and Drews, 2004). The low number of nesting females in recent years has decreased visitation to the Park, affecting the income of 31 community guides currently working in the Park (BIOMARCC *et al*., 2013).

In recent years, beaches such as Nombre de Jesús and Zapotillal, located 12 km north of the PNMB, have experienced an increase in visitation to observe the nesting of black turtles (*Chelonia mydas agassizii*). Between 2012 and 2016, no less than 21,365 people visited these beaches in the company of local guides, paying an average of US$45 per person and generating operators an approximate gross income of US$860,600.

Massive synchronized nesting (arribadas) of ridleys turtle in the Ostional National Wildlife Refuge, Costa Rica, contribute to the economic development and the quality of life of the community. Between 2013 and 2015, the gross income of the Ostional Integral Development Association was US$1.367.697. 70% was distributed among members of the community and 30% was left for the association, investing 14% in community work and student aid (ADIO *et al*., 2016). The Ostional experience is an example of community organization, participatory management, and inter-institutional collaboration.

In Panama, the interest to insert responsible sea turtle sighting as a tourism attraction has advanced the trainning of eco-tourist guides. In Playa Malena, since the year 2002, a community project has been executed that has successfully taken advantage of sea turtle nesting, which generates economic benefits through responsible tourism activities (Spotila, 2004).

X. HUMBOLDT SQUID

The Humboldt squid (*Dosidicus gigas*) is the main species of squid caught in the ETP, representing an important fishing resource, due to its abundance and large size (Jiménez, 2016). Its total length becomes greater than 2 m and it weighs up to 50 kg (Zeidberg and Robison, 2007).

Humboldt squid
Dosidicus gigas

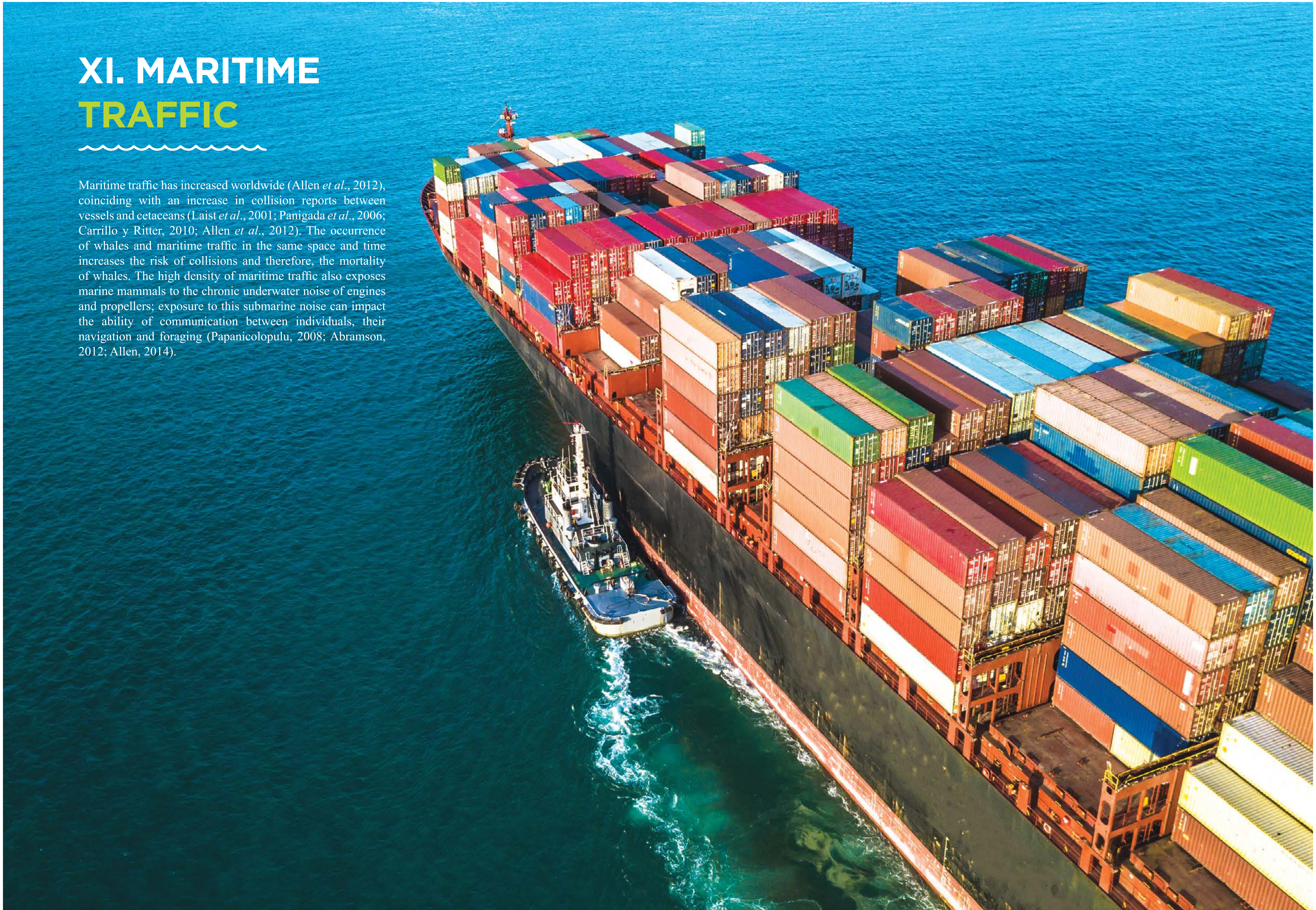
This squid is a highly migratory predator, which has adapted to the hypoxic conditions (low oxygen concentration) found in the Dome and that could be detrimental to its competitors and predators. (Stewart *et al*., 2014; Fiedler *et al*., 2017).

The giant squid congregates at the western edge of the Dome, above 100 m depth, in water masses with high concentrations of chlorophyll and temperatures of 17-22˚C (Ichii *et al.*, 2002; Waluda and Rodhouse, 2006). The Dome is considered as a potential spawning area for the species, due to the presence of high proportions of adult squid, paralarvae and the high productivity of the upwelling zone (Chen *et al*., 2013; Liu *et al*., 2013; Jiménez, 2016). For 1980 the catches in the ETP were of about 19,000 t and they were increased to 121.00 t in 1996, fluctuating between 82,000 and 166,000 t/year. (Jiménez, 2016).

Humboldt squid
Dosidicus gigas

XI. MARITIME TRAFFIC

Maritime traffic has increased worldwide (Allen *et al*., 2012), coinciding with an increase in collision reports between vessels and cetaceans (Laist *et al*., 2001; Panigada *et al*., 2006; Carrillo y Ritter, 2010; Allen *et al*., 2012). The occurrence of whales and maritime traffic in the same space and time increases the risk of collisions and therefore, the mortality of whales. The high density of maritime traffic also exposes marine mammals to the chronic underwater noise of engines and propellers; exposure to this submarine noise can impact the ability of communication between individuals, their navigation and foraging (Papanicolopulu, 2008; Abramson, 2012; Allen, 2014).



The Central American region is an area of particular importance for maritime traffic, due to the influence of the Panama Canal. It is estimated that 5% of world trade crosses the canal, with 40 vessels per day and an average of 14,000 vessels per year (Logística, 2012).

Important maritime routes cross the Dome region, boats sailing from the east coast of the American continent with the west coast, between North and South America, between the east of the American continent and Asia and between Europe and Asia (Fig. 24).

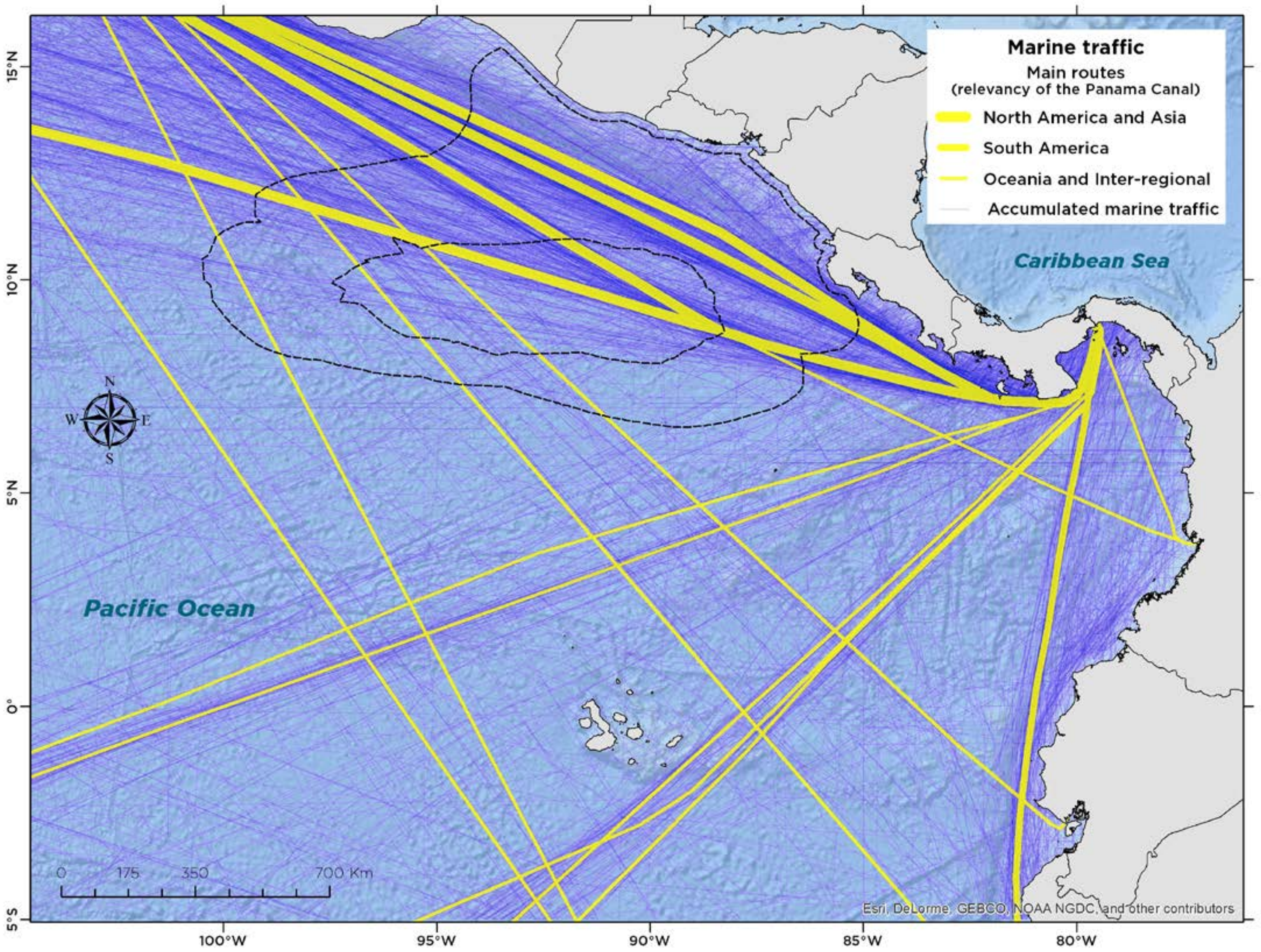


Figure 24. Main liner routes through the Dome.

To reduce this type of negative interactions it is important to consider routes that avoid areas of concentration of whales; establish dynamic areas of management that allow regulation to vary according to the spatial-temporal distribution of whales, such as speed reduction and the use of mechanisms for submarine noise reduction (Abramson, 2012).

Transit Separation Devices (TSD) are used around the world to reduce sonic pollution and the likelihood of collisions with marine wildlife when transiting whale aggregation zones (Abramson, 2012; Allen, 2014). This initiative has already been implemented in the region in order to reduce the effect of maritime traffic on visiting populations of humpback whales (*Megaptera novaeangliae*) in the Gulf of Panama (Fig. 25) (Guzman *et al*., 2013) and zones of aggregation of dolphins and humpback whales in the South Pacific of Costa Rica (Executive Decree 41003 MOPT-SP-MINAE).

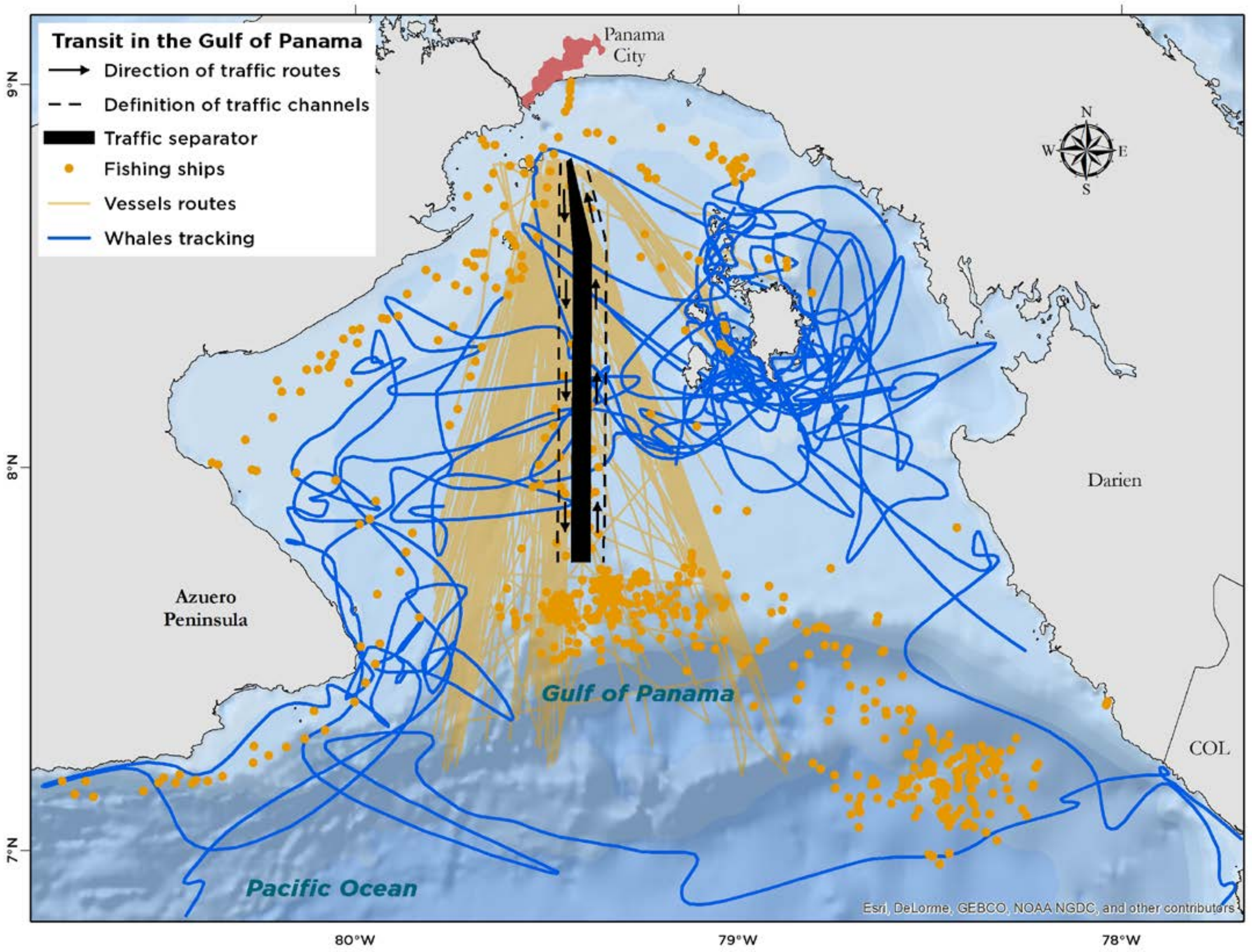


Figure 25. Transit routes of 892 vessels leaving the Panama Canal superimposed on the routes of 12 humpback whales in the same period with the DST for the Panama Canal (adapted from Guzmán *et al*., 2013).

Order maritime traffic for the protection of large cetaceans in the Eastern Pacific

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Smithsonian Tropical Research Institute, Panamá

The collision with merchant ships along their migratory route is a threat to many species of Eastern Pacific whales. This risk has increased with the expansion of maritime traffic near the coastal zone. in particular, tthe blue, gray and humpback whales are highlighted. All these species are protected internationally and, apparently, their populations recover within the region.

The humpback whale (*Megaptera novaeangliae*) and the gray whale (*Eschrichtius robustus*) present possibly the highest record of accidents and deaths in the Eastern Pacific. There are no clear statistics, because the majority of the collisions go unnoticed. However, these could not be the case of the blue whale (*Balaenoptera musculus*), due to its large size.

These three species make impressive migrations of thousands of kilometers, from the feeding areas in the Northern and Southern hemispheres, to the breeding areas in tropical and sub-tropical waters of the Eastern Pacific. In particular, the waters of Central America are visited annually by hundreds of whales, some with markedly coastal routes, while others with more oceanic routes, towards high productivity areas such as the Thermal Dome in Costa Rica. This creates a challenge on an unprecedented scale, for the protection of the great whales of the region. This will not be an easy task, because there are economic interests that must be weighed in and, in some cases, there is no adequate scientific information.

Several countries of the region (i.e. Chile, Peru, Ecuador) have implemented routing systems known as Traffic Separation Devices (TSD), which function as virtual avenues with exclusive navigation lanes. Areas to be Avoided (ATBA) have also been implemented, which are large areas where access to large vessels is limited. These systems have been mainly justified to improve safety in navigation in navigation, the orderly approach to ports, and to avoid accidents that could affect sensitive marine ecosystems.

Countries like Canada, United States, Costa Rica and Panama have taken advantage of, and justified these systems in order to reduce collisions with cetaceans. However, Panama and Costa Rica are the only countries that have based the justification in maps of coastal habitats, developed with data from marked humpback whales, followed by satellite transmitters, achieving its adoption by the International Maritime Organization (IMO) of three DST in 2014 and one ATBA in 2017, respectively. Studies done in Panama, where the possibility of collisions between ships and whales was modelled, both followed by satellites, demonstrated that the movements of whales (adults and offspring) in the Gulf of Panama, coincide with the main commercial maritime routes, which by implementing these routing systems, the area of possible collisions with whales could be reduced by 93%.

These results pave the way, in part, to consider maritime route systems adopted by the IMO in some key sites in the region, such as the coasts of Peru, Ecuador and Mexico, as well as the oceanic area of the Thermal Dome in Costa Rica.

Underwater noise as a threat to marine biodiversity

Lindy Weilgart y Silvia Frey.
OceanCare.

Marine animals, particularly whales and dolphins, but also fish, squids and other invertebrates, depend on sound for all their essential functions such as search for food, predator evasion, mating, group coordination, navigation and perception of their surroundings. These animals "see" with their ears, due to the low amounts of light found below the water. Sound, in contrast, travels very fast and very far underwater in comparison with air, almost five times faster. Theoretically, blue whales communicate across an entire ocean. Humans add noise to the ocean, degrade the habitat of many species, "blinding them" to a certain degree from important information, whether because they damage their hearing, or because they "drown" valuable sounds, by masking them, making their survival more difficult.

The noise caused by human beings comes, mainly, from commercial traffic, seismic exploration by oil and gas, naval and mapping sonars, small vessels, construction and oil extraction. In general, the marine sound has increased 100 times in some areas since the industrial era, doubling its intensity every decade during the last decades. Seismic exploration can be heard at distances of 4,000 km in some areas. The US Navy Active Low-Frequency Sonar can cover an area of 3.9 million de km^2, at levels that are known to disturb the whales.

Scientific expedition to the Thermal Dome of Costa Rica

Impacts in marine life include fatal stranding or deaths at sea, hearing damage, long term evasion of noisy zones, stress (which can affect reproduction, the skill to fight against diseases and infections, and cause premature aging), reduction in the capacity for feeding and reproduction, migratory changes, and mayor energy costs.

Many dolphins that run aground or become entangled in fishing gear show deep hearing loss, suggesting that the hearing damage may have contributed to the stranding or entanglement. Even the well-being of populations (birth rates, mortality rates, growth rates) can be affected. Studies in fishes and whales show an increase in stress hormones, disruption in behavior, deteriorated development, and increase in fish embryonic mortality, as they are subjected to maritime traffic noise.

Different noise sources require different solutions. For maritime traffic, the sound produced is not intentional and its causes probably reduce the efficiency in the use of fuel. Better technologies are possible and are the focus of studies today. The IMO is slowly addressing the issue of noise in marine traffic, and voluntary guidelines are being developed.

To address the noise produced by seismic surveying, there are alternatives to air guns, such as Marine Vibroseis, which could have a lesser impact in marine life. For marine animals that migrate seasonally, seasonal programming of activities that generate noise, would avoid its overlapping with the presence of marine animals. Vital areas and seasons for reproduction and feeding, should be avoided whenever possible. The few sites that are still relatively silent should be preserved as acoustic shelters. In order to preserve the biodiversity from the impact of the noise, precautionary management must be used before expecting irrefutable biological evidence of the impact.

XII. MAIN CHALLENGES IN THE MANAGEMENT OF THE DOME

Mixed legal nature.

The Dome is located mostly in ABNJ, beyond the 200 nautical miles established by the United Nations Convention on the Law of the Sea (UNCLOS) as territorial seas and exclusive economic zones of the States (Fig. 26).

Submarine Continental Shelf

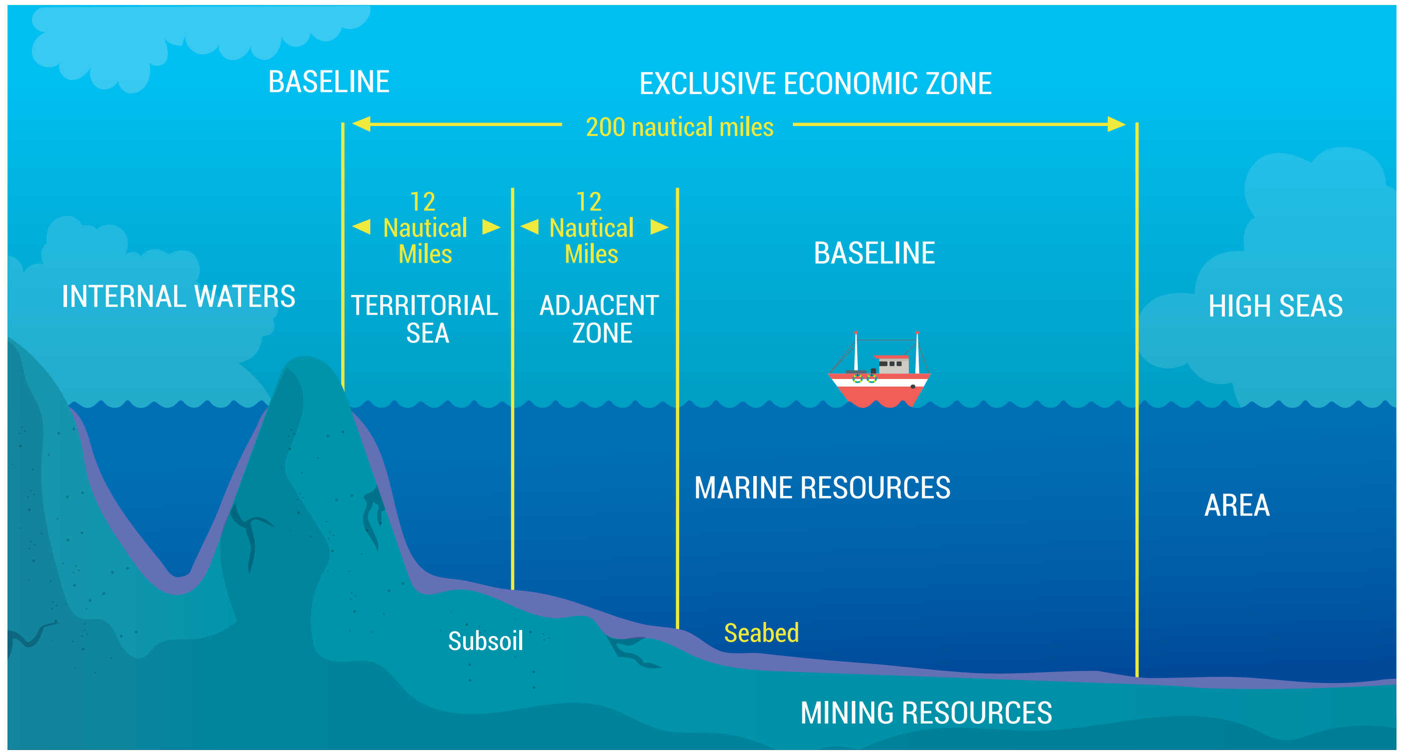


Figure 26. The zoning of marine waters according to the UNCLOS.

Being part of the ABNJ, the Dome faces the absence of a regulatory framework that allows the control and planning of the activities carried out in it. The management and use of biodiversity in the high seas are not regulated by any specific international instrument.

The United Nations (UN) is in the process of establishing a legally binding international instrument for the conservation and sustainable use of marine biological diversity in ABNJ (commitment made during the United Nations Conference on Sustainable Development, The Future We Want, 2012). If achieved, this would be the third implementation agreement within the framework of UNCLOS (AIC III). Among the issues to be addressed in this agreement are: i) marine genetic resources, including issues related to the distribution of benefits, ii) management mechanisms based on geographical zones, including marine protected areas, iii) assessments of environmental impact and iv) capacity building and transfer of marine technology.

The changing nature of the Dome, which during periods of maximum extension covers part of the jurisdictional waters of all the Central American countries (Jiménez, 2016), It brings together two different types of legal systems for its management.

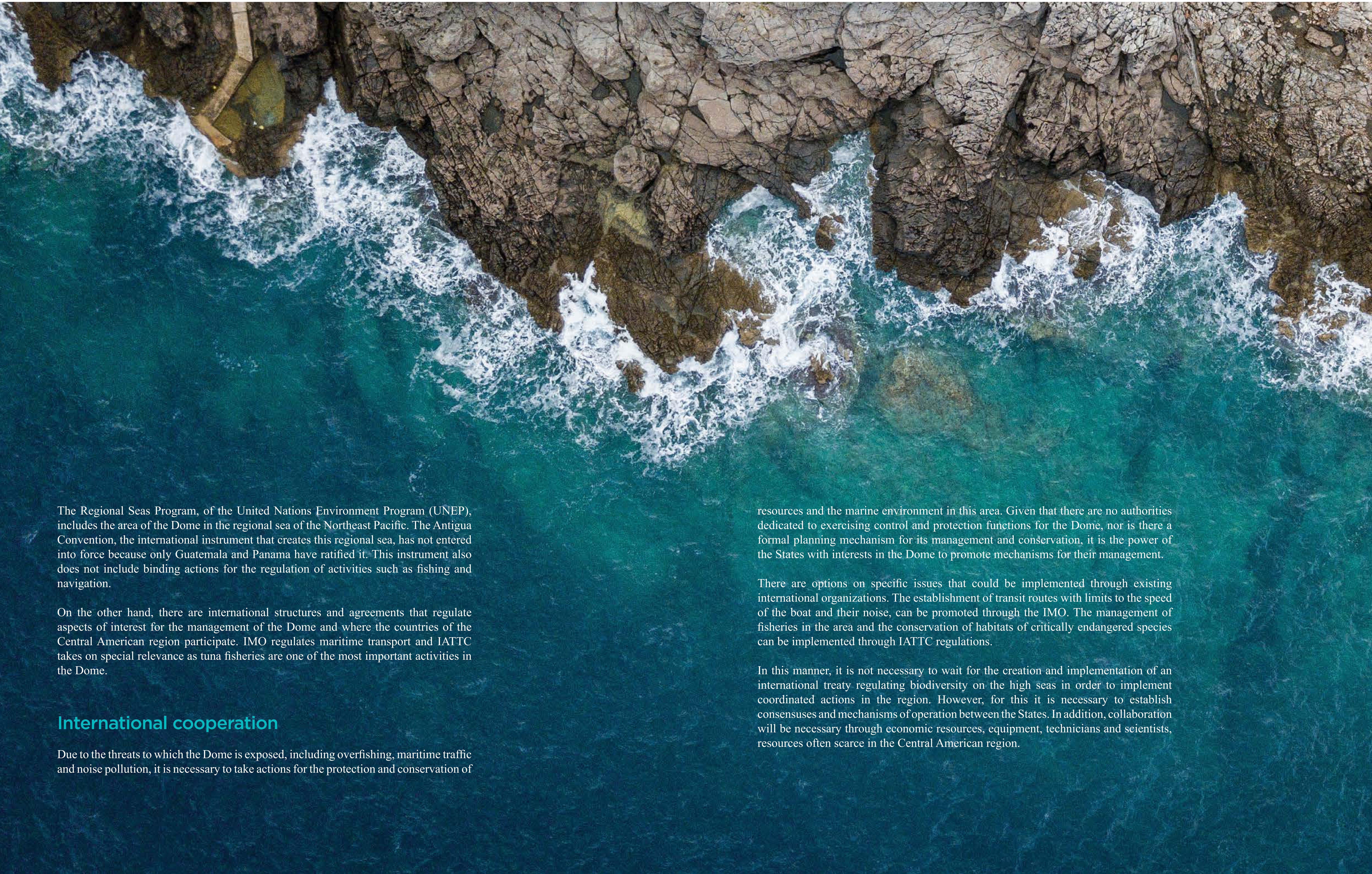
On the one hand, each of the jurisdictions of the States, in which the Dome is temporarily extended, has different specific regulations and different authorities for its application. On the other, the ABNJ, when considered a common good (*res communis*), are not under the jurisdiction of any State. The absence of a mechanism that protects marine biodiversity in the High Seas, has raised questions about whether the current governance structure will ensure the conservation of the biological resources associated with this vast space, in light of the growing maritime traffic, fishing exploitation and the effects of climate change.

Bigeye thresher
Alopias superciliosus

Fragmented management

The Central American region has different regional and international organisms and mechanisms for the management and protection of marine resources. However, these are entities specialized in specific issues that have been organized through structures that do not necessarily consider the particularities of the ABNJ. Additionally, there is no specific structure or program for the management of the Dome.

At the regional level, within the Central American Integration System (SICA), there are different bodies related to marine resources. The Central American Commission for Environment and Development (CCAD) has among its objectives the conservation and environmental management, including marine issues in jurisdictional waters of member countries. For its part, the Organization of the Fisheries and Aquaculture Sector of the Central American Isthmus (OSPESCA) is dedicated to the sustainable development of fishing and aquaculture activities and the Central American Commission of Maritime Transport (COCATRAM) deals with issues related to maritime and port development of American Center.



The Regional Seas Program, of the United Nations Environment Program (UNEP), includes the area of the Dome in the regional sea of the Northeast Pacific. The Antigua Convention, the international instrument that creates this regional sea, has not entered into force because only Guatemala and Panama have ratified it. This instrument also does not include binding actions for the regulation of activities such as fishing and navigation.

On the other hand, there are international structures and agreements that regulate aspects of interest for the management of the Dome and where the countries of the Central American region participate. IMO regulates maritime transport and IATTC takes on special relevance as tuna fisheries are one of the most important activities in the Dome.

International cooperation

Due to the threats to which the Dome is exposed, including overfishing, maritime traffic and noise pollution, it is necessary to take actions for the protection and conservation of resources and the marine environment in this area. Given that there are no authorities dedicated to exercising control and protection functions for the Dome, nor is there a formal planning mechanism for its management and conservation, it is the power of the States with interests in the Dome to promote mechanisms for their management.

There are options on specific issues that could be implemented through existing international organizations. The establishment of transit routes with limits to the speed of the boat and their noise, can be promoted through the IMO. The management of fisheries in the area and the conservation of habitats of critically endangered species can be implemented through IATTC regulations.

In this manner, it is not necessary to wait for the creation and implementation of an international treaty regulating biodiversity on the high seas in order to implement coordinated actions in the region. However, for this it is necessary to establish consensuses and mechanisms of operation between the States. In addition, collaboration will be necessary through economic resources, equipment, technicians and scientists, resources often scarce in the Central American region.

Governance

The different threats to biodiversity and ecosystems dependent on the Dome, have made it necessary to discuss new models of governance, where the best mechanisms and practices for the protection of the Dome are established both in the different jurisdictions of the countries, and in the area of high seas.

Effective coordination between the different public and private actors, as well as international cooperation are fundamental elements to ensure the sustainability of the marine resources that benefit from the Dome and, therefore, the environmental services and productive activities they support. The relevance of the Dome for the region demands the urgent creation and implementation of conservation and management measures both from the Central American States and from the competent regional and international organizations.

The experiences of governance in other marine regions have shown that it is necessary to consider the establishment of some kind of international legal instrument that clarifies who is responsible for the management and assurance of the sustainable use of their resources.

When dealing with issues of Public International Law, states are bound internationally to the extent that they have given their consent to do so (Tomuschat, 1976). In this way, any decision that is established for the management of a common resource, such as the Dome, must have the consensus of the countries involved.

It is also necessary to establish international cooperation processes that take advantage of the institutional framework and existing international regulatory frameworks, promoting an active cooperation among the States, in order to make their management effective. (Jiménez, 2016). It should also consider actors as diverse as the scientific sector or coastal communities and the Regional Fisheries Management Organizations (RFMOs), which can contribute to the construction of a governance mechanism.

Ridley turtle.
Lepidochelys olivacea

On the other hand, it is fundamental to consider which will be the governing body of the governance model. The conventions or agreements have been the most used figures to administer the ABNJ. These are usually made up of a Secretariat that deals with the operational issues of the agreement and a conference that brings the Parties together periodically to make decisions of a political nature. In most of these figures there is a Scientific Commission, which provides technical inputs for decision making.

Under this idea, there are 3 options: administer the Dome in a coordinated manner among all interested States, create a new structure or regional governance body or include the administration of the Dome within an existing regional or international body.

In any case, a model of governance for the Dome will require the designation of a form of financing. The financing of marine governance structures is generally composed of a core budget, fed by contributions from member countries and from programmatic funds generated by the Secretariat or through collaborative agreements with existing organizations that allow the redirection of resources towards the specific needs of the region. ABNJ to handle.

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Sailfish
Istiophorus platypterus

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