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Preventing plastics pervading an oceanic oasis: Building the case for the Costa Rica Thermal Dome to become a World Heritage site in ABNJ

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ABSTRACT

World Heritage status for selected sites in Areas Beyond National Jurisdiction is under active consideration, and the Costa Rica Thermal Dome in the eastern tropical Pacific Ocean is a feasible candidate site. A scientific expedition to the area in April 2017 added to biological baseline data but also confirmed presence of microplastics in the water column. National and regional efforts are being made by Central American countries to strengthen mechanisms for integrated ocean management, educate coastal communities and give early consideration to potential future threats such as ocean fertilisation. This paper concludes that to achieve World Heritage status for this iconic site requires an entity to both propose the area and report on its status. Bringing into force the Antigua Convention, a Regional Seas Convention for the Eastern Tropical Pacific, would provide an appropriate platform for Central American governments to enact protective measures.

1. Introduction

Since 1972 the World Heritage Convention has recognised the Outstanding Universal Value (OUV) of more than 1000 cultural and natural locations including the World Heritage marine network. Currently, 49 marine sites distributed across 37 countries are inscribed on UNESCO's World Heritage list [1]. They include a number of extensive recent listings in remote ocean regions. All are recognised for their unique marine biodiversity, singular ecosystem, unique geological processes or incomparable beauty [2].

However, in common with most Marine Protected Area (MPA) networks, the World Heritage marine network has recognised gaps within national jurisdictions [3,4] and currently there is no coverage in Areas Beyond National Jurisdiction (ABNJ). Freestone et al. [5] consider the absence of World Heritage sites in the high seas as an historical oversight. Their legal analysis finds nothing to prevent the recognition of natural or cultural OUV in ABNJ, albeit that the primary obligation to propose, assess and inscribe sites is placed on States (i.e., within their national jurisdictions). Conservation priorities have expanded in recent years to include highly dynamic pelagic ecosystems in the high seas [6], but the relatively poor understanding of both the ecology and uncertain legal status of biodiversity in the high seas make these ecosystems vulnerable to pressures such as pollution and overfishing, and more recently to deep-sea mining [7,8].

Freestone et al. [5] select five sites to illustrate potential OUV in the high seas, one of which is an oceanographic feature known as the Costa Rica Thermal Dome (hereafter ‘the Dome’). The Dome is a dynamic yet persistent offshore upwelling system that plays a significant role in the ecological functioning of the eastern tropical Pacific Ocean. Its diameter oscillates annually between 200 km and 400 km [9], with a core area of approximately 55,000 km^2, the typical position of which is located around 9° N and 90°W [10]. The whole feature extends mostly over ABNJ, but can often extend into the Exclusive Economic Zones (EEZ) of several Central American countries.

The underlying causes for of this distinctive oceanographic feature are the interaction between the ocean and the atmosphere, and the specific circulation patterns in the eastern tropical Pacific Ocean [11]. Such patterns are strongly influenced by Central American wind jets that may attain speeds over 20 ms^{-1} and extend seaward over hundreds of kilometres [12]. Interaction between all these factors causes the

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Table 1
Guidelines and considerations developed by the 2011 expert workshop on pelagic EBSAs [14].

Guidelines	
Size matters	The scale of pelagic features and life-history stages can be 1000–10,000 s km^2, delineation of EBSAs must match these scales
Consider time	The pelagic ocean is highly dynamic, consideration must be given to how features and organisms move over time
Think deeply	The average depth of the ocean is 3700 m, the delineation of pelagic EBSAs should not solely consider surficial elements
Be dynamic	The use of oceanographic variables that vary over space and time to delineate EBSAs is possible and encouraged
Quantify uncertainty and be adaptive	Given the relative lack of data for the pelagic realm, there is an increased need to build uncertainty into the EBSA identification process. Further there is a need to ensure the process is adaptive and ongoing so adjustments can be made as new data become available
Other considerations	
Not all phytoplankton are created equal	Areas of interest likely involve some level of trophic transfer, not just high productivity
Prioritise complexity	Areas where currents, frontal systems or eddies meet complex topographic features tend to produce areas of particular ecological interest
Process drives pattern	Appropriate consideration should be given to the underlying processes that result in an area meeting the EBSA criteria

localised upwelling of cold nutrient-rich waters towards the sunlit surface, fuelling a frenzy of biological productivity that attracts fish and their predators from far and wide [13].

In 2011, deliberations to scope areas of particular significance to biodiversity in the pelagic realm concluded in the production of a series of guidelines and other considerations [14] (summarised in Table 1). The Dome was highlighted as an example of thermocline shoaling and complex eddies and eddy fields exhibiting offshore upwelling and downwelling [14–16]. Later, in August 2012, a Convention on Biological Diversity (CBD) Regional Workshop to describe Ecologically or Biologically Significant Marine Areas (EBSAs) in the eastern tropical and temperate Pacific Ocean included a description of the Dome, recognising its distinct oceanographic signature and highlighting it as a year-round habitat for endangered blue whales (*Balaenoptera musculus*) and as an important part of a migration path for leatherback turtles (*Dermochelys coriacea*) [17] (Table 2). A more recent US National Oceanographic and Atmospheric Administration (NOAA) Technical Memorandum [18] confirms the critical importance of the Dome and associated areas for several cetacean species. Other species noted include short-beaked common dolphins (*Delphinus delphis*), yellowfin tuna (*Thunnus albacares*) and jumbo flying squid (*Dosidicus gigas*). The CBD's EBSA description also recognises the connection between the Papagayo coastal upwelling region inshore and the offshore oceanic waters of the Dome, and incorporates both into a large polygon.

Known pressures on biodiversity from human activities taking place in the Dome are commercial fisheries and international shipping. The fisheries target tuna, mahi-mahi and squid, although recent reports suggest that only 9.1% of stocks are fished at unsustainable levels in the eastern central Pacific [19]. The proximity of the Dome to major shipping routes converging on the Panama Canal raises likely impacts of underwater noise and increases probability of ships striking marine animals. Chronic microplastic pollution is also likely, but has yet to be confirmed. Synthetic polymers such as nylon and polypropylene are buoyant in seawater, and even heavier polymers float just below surface layers [20]. As such, they are likely to be driven by ocean currents, with higher levels expected to be associated with oceanic convergent features such as the anticyclonic eddies influencing the Dome [21].

This article presents the findings of a recent oceanographic expedition to the Dome, whose primary mission was to acquire new information to complement the CBD EBSA description. By documenting the presence of megafauna (e.g., cetaceans, sharks, sea turtles) and attesting the presence of microplastics, the acquired evidence will serve to confirm the ranking of the Dome against the EBSA criteria [17] (Table 2). In addition, this information will be used to assess and promote the Dome's potential for World Heritage status in the context of conservation priorities in the high seas, with particular focus on the ever-growing concern of plastic pollution around the globe.

2. A survey to add new evidence

An oceanographic survey expedition to the Dome was conducted on 3–6 April 2017 by Fundación MarViva of Costa Rica, the timing of which was informed by remotely sensed sea-surface temperature data showing the core area of the Dome close to the Costa Rica coast (Fig. 1). The survey was part of a project led by the Global Ocean Biodiversity Initiative (GOBI) and funded by Germany's International Climate Initiative (BMUB-IKI). The ultimate aim of the project is to devise and promote a governance scheme in the high seas area of the Dome. This is consistent with guidelines issued by the World Heritage Committee that encourage capacity building and international research cooperation needed for the effective implementation of the World Heritage Convention [22]. Participants in the survey included representatives from GOBI, the US National Oceanic and Atmospheric Administration, the Universidad de Costa Rica, the Universidad Nacional, Fundación Keto, Asociación Misión Tiburón and Fundación MarViva.

The objectives of the survey were to: (i) record the presence of megafauna and, where possible, tag individuals to learn about their behaviour and relationship with the Dome, (ii) collect phytoplankton and zooplankton samples, and (iii) sample for microplastics to ascertain their presence. On-board activities conducted towards the attainment of those objectives are described below.

Table 2
Summary of EBSA criteria describing the Dome [17].

EBSA criteria	Expert ranking	Explanation (main points)
Uniqueness or rarity	High	Shoaling thermocline forced by the Papagayo wind jet provides a unique blue whale habitat year-round for mating, breeding, calving and raising calves
Special importance for the life-history stages of species	High	Vital for blue whales and connectivity with Baja California populations. Section of migration pathway for Leatherback turtles
Importance for threatened, endangered, or declining species and/or habitats	High	Eastern North Pacific blue whale population is the only known population showing recovery, thus recovery worldwide may depend on this area
Vulnerability, fragility, sensitivity or slow recovery	High	Overfishing and other threats including by-catch of turtles and possibly climate change
Biological productivity	High	High primary production leading to high zooplankton biomass
Biological diversity	Don't know	Yet to be comprehensively described and little information on benthic biodiversity
Naturalness	Don't know	Further evaluation needed

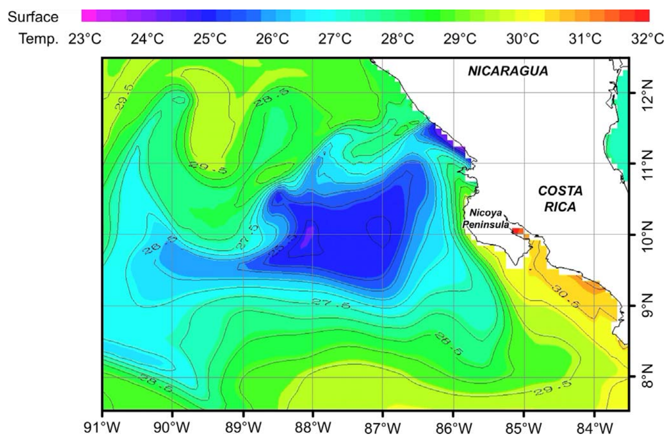

Fig. 1. Thermocline profile for surface waters of the eastern tropical Pacific Ocean on 30 March 2017 (source: MIO CIMAR).

2.1. Observation and tagging of megafauna

Throughout the expedition, observers were on duty during transits and at sampling sites, recording the presence and location of any visible megafauna. In total, 11 species of megafauna were recorded, including mammals, fish, sharks and sea turtles. Three species of dolphins were identified, including the common bottlenose dolphin (*Tursiops truncatus*), the pantropical spotted dolphin (*Stenella attenuata*), and the short-beaked common dolphin (*Delphinus delphis*). Additionally, there were two sittings of unidentified beaked whales (Ziphiidae) and one unidentified dolphin (Delphinidae). Five different species of pelagic fish were recorded, including two species of sharks (silky shark *Carcharhinus falciformis* and pelagic thresher shark *Alopias pelagicus*), two billfish species (Indo-Pacific sailfish *Istiophorus platypterus* and swordfish *Xiphias gladius*), and one giant manta ray (*Manta birostris*). Three Olive Ridley turtles (*Lepidochelys olivacea*) were recorded, two of which were tagged with satellite transmitters and their movements recorded (Fig. 2).

2.2. Plankton sampling

Phytoplankton samples were obtained at 14 sampling sites, spaced approximately 50 km apart along the transit route to and from the Dome (Fig. 3). At each site, a 1 L water sample was collected at a depth of 80 m using a Niskin bottle. The samples were fixed with acidic Lugol's iodine solution and examined under the microscope to identify species. Zooplankton samples were obtained using a midwater plankton trawl, in keeping with previous studies [23], at each of the 14 sampling sites. Each trawl involved the deployment of a plankton net with a 200 μm mesh over a distance of 80 m. On retrieval, zooplankton samples were fixed with a 4% formaldehyde solution. In the laboratory back on land, zooplankton samples were fractioned with a Folsom Plankton Sample Splitter [24], taking a 1/32 fraction from the sample at site 1, and a 1/8 fraction from the rest, and then dried at 60 °C to determine dry weight and estimate biomass. Intending no quantitative analysis, the samples were examined visually to determine organism presence, taking 5 ml from homogenised samples.

These analyses revealed that phytoplankton diversity was dominated by picophytoplankton (< 2 μm cells), specifically *Synechococcus* spp. Standardised mean biomass of zooplankton per sample was $3.34 \pm 2.36\,\mathrm{mgm^{-3}}$ (Table 3), with samples containing individuals of the order Euphausiacea and of subclass Copepoda from the families Oncaeidae, Corycaeidae and Eucalanidae.

2.3. Microplastic analysis

Microplastic samples were acquired by subsampling 13 of the 14 zooplankton trawl samples. Analysis for microplastics involved filtering the samples using Whatman GF/A filter paper [25]. The filter papers were analysed using light microscopy down to x60 magnification and observed plastic particles classified by size (recording the longest

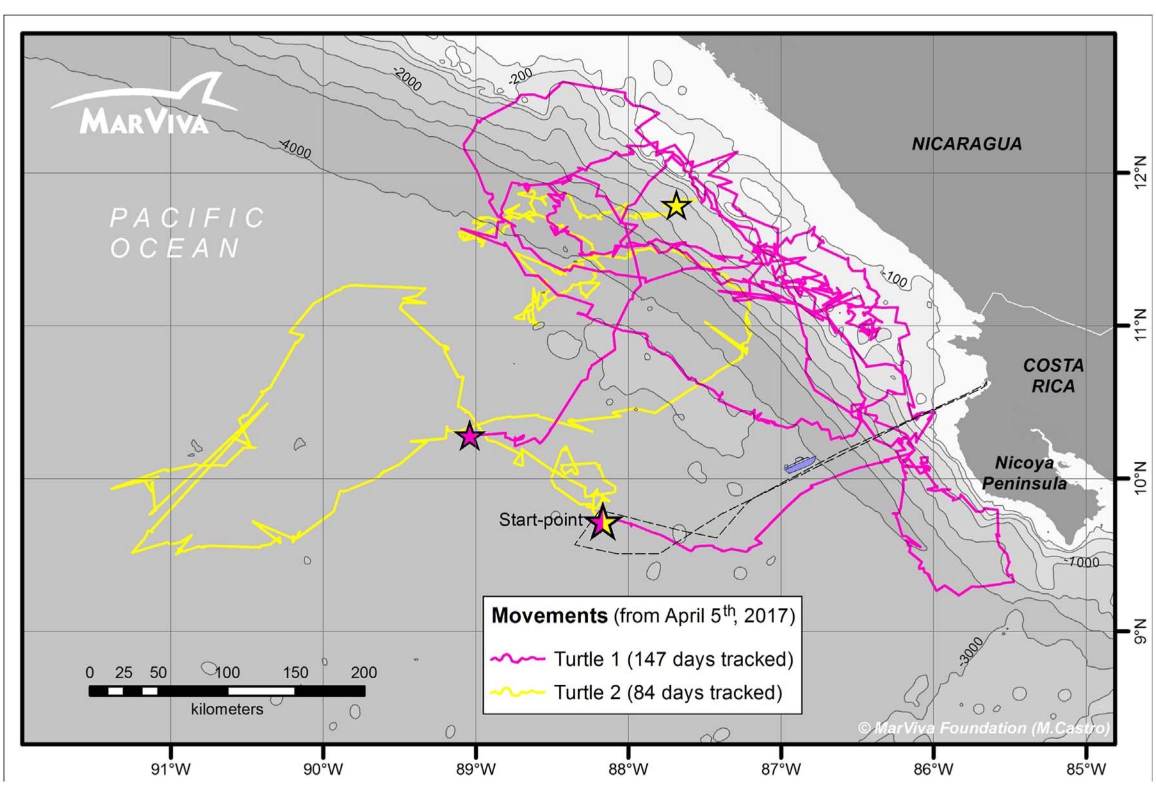

Fig. 2. Movements of olive Ridley turtles tagged during the 2017 expedition.

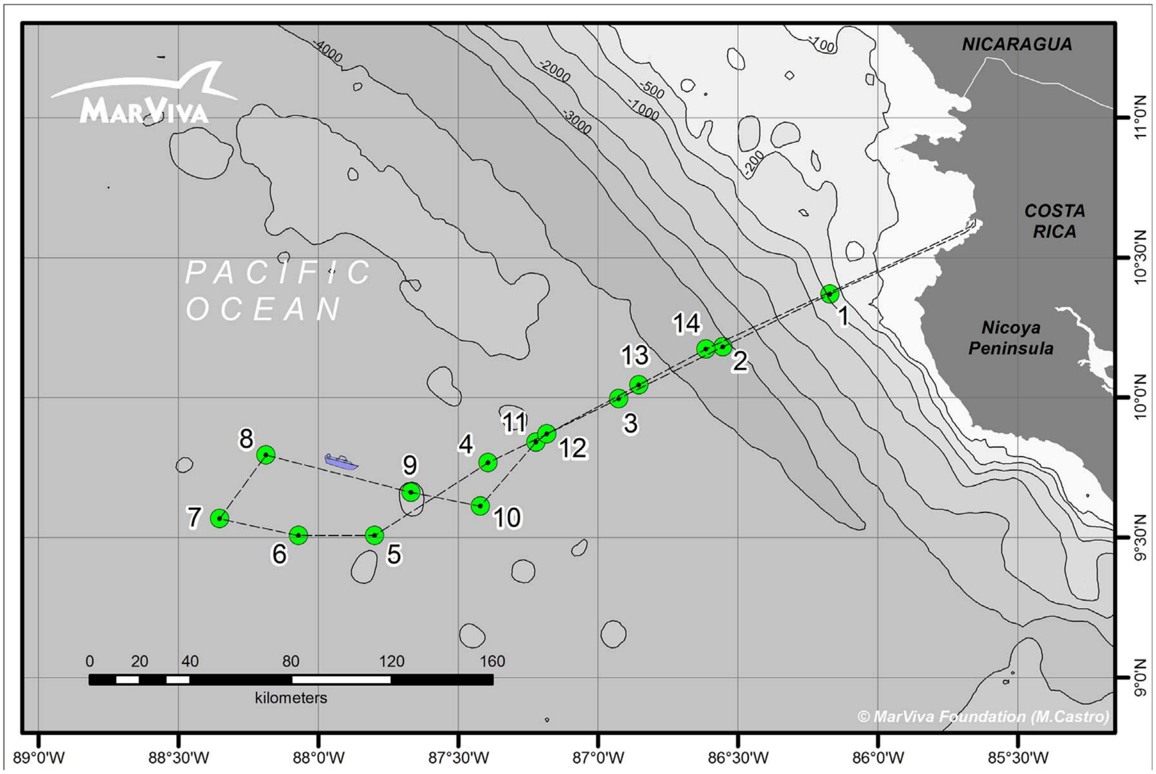

Fig. 3. Location of plankton and microplastic sampling stations.

Table 3
Measured zooplankton biomass by sampling site.

Site	Latitude (N)	Longitude (W)	Depth	Total sample biomass (mgm^{-3})
1	10 22.196	86 10.244	80	7.8524
2	10 10.869	86 33.241	80	3.6609
3	09 59.759	86 55.571	80	2.0692
4	09 46.020	87 23.587	80	8.7543
5	09 30.431	87 47.959	80	1.6447
6	09 30.397	88 04.251	80	2.7589
7	09 34.023	88 21.189	80	1.6447
8	09 47.676	88 11.239	80	1.5386
9	09 39.705	87 40.140	80	2.2814
10	09 36.708	87 25.265	80	1.6447
11	09 50.445	87 13.340	80	2.9181
12	09 52.244	87 10.985	80	5.5179
13	10 02.700	86 51.250	80	1.9100
14	10 10.391	86 36.849	80	2.5998
			Mean:	3.3425 ± 2.35719

dimension); shape (irregular; rounded; or fibrous) and colour (for further information see Gallagher et al. [26]).

In total, 206 microplastic particles were recorded (Table 4), and their presence observed in all microplastic samples. Relatively high scores of particles were seen in samples 2, 5, 6, 12, 13 and 14. Of the 206 recordings, all but one of those particles was fibrous in nature, the outlier being an irregular blue shape particle found in Trawl 11. No regular shaped particles (virgin microplastics from pellets) were recorded in any of the samples.

3. Discussion

Further to reviews of the EBSA process [27–29], supplementary work is needed to exemplify additional utility of EBSA descriptions for large pelagic features such as the Dome: drawing them to the attention of relevant Ministries in littoral States; providing a focus and funding for scientific study (understanding more); using such locations as a basis for advocacy (to raise public awareness); and highlighting the need for intervention by competent international organisations through sectoral partnerships (e.g., monitoring, control and surveillance of fisheries to stamp out illegal, unreported and unregulated fishing). To this end, working with FAO and UN Environment, the CBD has orchestrated a Sustainable Ocean Initiative Global Dialogue to bring together sectoral ocean interests. For the central eastern Pacific Ocean, integrated ocean management has been the motivation for efforts by Fundación MarViva since 2012, latterly supported by GOBI-IKI. In the lead-up to the expedition reported here, Fundación MarViva has organised regional workshops in South and Central America to promote the discussions held at the United Nations, published a book describing the ecosystems of the Dome [30], advocated governance for the High Seas area of the Dome in international venues (CBD, CPPS,[1] UNESCO, BBNJ PREPCOM[2]), and facilitated research by young scientists. Specific challenges and threats are set out below.

3.1. Challenges for managing pelagic habitats in ABNJ

Most blue whale habitat, including the Dome, has no formal protection. Given the distances covered by these animals, scattered distribution of risks, and a dearth of scientific data, designation of a marine protected area is not necessarily easy to conceptualise and may not always be the most appropriate area-based management tool. The Dome is intrinsically connected to biodiversity in other areas, most specifically to populations of blue whales along the western coast of North America, but also to the suite of Centro-American turtle nesting beaches. For turtle conservation, specific self-contained protected

[1] CPPS: Permanent Commission for the South Pacific.

[2] BBNJ PREPCOM: Preparatory Committee established by General Assembly resolution 69/292 for the Development of an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine Biological diversity of areas Beyond National Jurisdiction.

Table 4
Total microplastic counts and descriptions by sampling site.

Site	Size category < 1 mm	1–2.9 mm	3–4.9 mm	5–7 mm	Total
1	1 red fibre	2 black fibres	2 black fibres		5
2	6 black fibres 1 red fibre	8 black fibres 1 blue fibre 4 clear fibres		1 black fibre	21
3	2 red fibres 3 black fibres	2 black fibres			7
4	2 red fibres 1 blue/black fibre 4 black fibres	2 red fibres 4 Black fibres	2 red fibres 1 blue/black fibre	1 black fibre	17
5	1 blue fibre 10 black fibres 1 red fibre	2 white fibres 1 blue/black fibre 2 red fibres	2 black fibres 1 red fibre		20
6	14 black fibres 1 blue fibre 1 red fibre 1 black/clear fibre	1 black/red 3 black fibres	1 red fibre		22
7	1 black fibre	3 black fibres	1 red fibre 1 blue/black fibre		6
8	3 black fibres	1 black fibre			4
9	12 black fibres 1 red fibre 1 white/blue fibre 1 blue fibre	1 white/clear fibre 1 blue fibre 1 red fibre	2 black fibres		20
11	3 black fibres 1 blue irreg. particl.	7 black fibres	1 black fibre		12
12	8 black fibres 3 red fibres	7 black fibres 2 red fibres 1 white/red fibre	1 black fibre 1 blue/black fibre	2 red fibres	25
13	9 black fibres 2 red fibres	1 white/red fibre 4 black fibres 1 red fibre 3 clear fibres			20
14	10 black fibres 1 red fibre	13 black fibres 2 white/clear fibres	1 black fibre		27
Total	105	80	17	4	206

locations within the Papagayo Upwelling EBSA are already in place. The Parque Nacional Marino Las Baulas and Parque Nacional Santa Rosa include marine protected areas that support important sea turtle nesting beaches, which may deserve enlarging or buffering from human impacts. Shillinger et al. [31] have demonstrated the need for sustained conservation of high use inter-nesting turtle habitats, such as Playa Grande in Costa Rica, from which the ocean currents act as 'hatchling highways' rapidly transporting young turtles offshore away from predators and increasing their survival expectancy. Concentrations of shark species are also an integral part of the Papagayo Upwelling EBSA; species such as the bull, silky, thresher, and white tip reef sharks visit or live in the area. The Área de Conservación Guanacuaste (ACG) protects the only archipelago in Costa Rica, known as Murciélagos Islands, which is an important cleaning station for bull sharks [32]. However, there is no protection currently for pelagic species. The results presented here from plankton sampling during the dedicated research cruise in 2017 conform with previous studies [33,34] that highlight dense populations of phytoplankton with dominance and high cell counts of the cyanobacteria *Synechococcus* sp. The abundance of phytoplankton strongly correlates with zooplankton abundance and the presence of grazing organisms such as krill (Euphausiacea). It is this localised availability of forage that concentrates megafauna at the upper layers of the Dome.

The designation of at least 10% coverage of marine protected areas in the high seas, as encouraged by CBD's Aichi Target 11 and Sustainable Development Goal 14, is proving elusive [35], prompting UN General Assembly resolution 69/292. The ACG, which harbours the birth of the Dome on the Pacific coast off Costa Rica, is one of 49 marine sites inscribed on UNESCO's World Heritage list representing the world's most iconic places and there is a scientific argument to extend and expand this designation offshore into ABNJ.

Freestone et al. [5] set out potential justification of World Heritage Criteria together with a brief note on geographic scale and site integrity. They note that "no management system is in place that could adequately protect the site's unique characteristics" (p. 34). Observations made during the present investigation add to the supporting evidence that would justify the Dome against World Heritage Criteria IX and X.[3]

It is essential that not only is the Dome recognised as important, but that human activities around it are also appropriately managed. In this respect the European concept of 'good environmental status' (GES), as set out in the European Union's Marine Strategy Framework Directive [36], is useful. Dickey-Collas et al. [37] argue that for pelagic habitats to be in GES and able to provide goods and services to humans, three conditions should be met: (i) that all species present under current environmental conditions should be able to find the pelagic habitats essential to close their life cycles, (ii) that biogeochemical regulation is maintained at normal levels, and (iii) that critical physical dynamics and movements of biota and water masses at multiple scales are not obstructed.

3.2. Threats from plastic pollution and ocean fertilisation

With few oceanic studies having focused on the levels of plastics contamination beyond the continental shelf [38], this study has shown both a presence of microplastics throughout the survey area, as well as relatively high particle counts at most of the sampling sites. Whilst it may be tempting to suggest that the predominance of fibrous plastic particles over other shapes is a matter of buoyancy and that there is a greater propensity for non-fibrous shapes to sink in neritic coastal waters (a process known as 'marine snow' [39]), it is really the case that more research is needed to understand fully the processes at work in different marine environments. The sampling site locations and predominant currents of the region also do not provide any real insight in to the sources, pathways or processes involved, though it is most likely that the source is land-based from river run-off [40] and transported far and wide by the dynamic hydrography of the region. This study does confirm claims that the oceans have become a 'plastic soup', with high levels of plastics being found throughout the high seas; a claim first made by Captain Charles Moore in 1997, on sailing through the North Pacific Gyre from Hawaii to southern California. Transportation of these particles of plastic down the water column is most likely driven by the flux of ingestion of zooplankton in the epipelagic and mesopelagic zones. As plastics become part of copepods faecal pellets [41], it is thought that they end up affecting carbon cycles of the deeper ecosystems.

Just as evidence is amassing on the physical effects of larger plastic debris on animal health and behaviour globally (see [42]), more research is required to establish the uptake of microplastics by biota within the Dome, as well as their ecotoxicological effects. There is already documented evidence relating to ingestion of microplastics by larger organisms [43–45], including the effects of different polymers

[3] Criterion IX: Significant Ecological and Biological Processes in the Evolution of Ecosystems, Communities of plants and animals; Criterion X: Significant biological diversity and threatened species of OUV.

[46], however, there is still a need to ascertain the levels of microplastic and associated chemical contamination within phytoplankton and zooplankton within the region, as well as how it might be transmitted up the food chain. Added to this, the specific gravity of some plastic particles is very similar to that of algae, so microplastics become potential prey analogues for phytoplanktivores [47]. In this context, Lusher et al. [48] advocate giving attention to standardisation of protocols (i.e., greater consistency and comparability in data collection and analysis) to ensure better assessment of risks posed to biota from microplastics.

To achieve solutions to plastic pollution, society needs to acknowledge land/sea interactions – to promote education, corporate responsibility, and civic transboundary actions. Costa Rica has a significant national agenda for mobilising efforts to tackle marine debris. This involves working with different sectors to transform consumption patterns. In addition to a law on Integrated Waste Management involving all sectors, Costa Rica has adopted the principle of Extended Producer Responsibility to hold producers responsible for 'end of life-cycle' waste [54]. On 5 June 2017, during the UN Ocean Conference, Costa Rica launched a national strategy discouraging the use of single-use plastic bags as part of an overall strategy to reduce by 30% plastic particles by cubic metre in the Pacific Coast sampling area by 2021 [55]. Other actions include specific institutional procurement rules, incentives for substitution of single-use plastics, publicising voluntary commitments, encouraging relevant research and communicating the results of all activities. All of these actions contribute towards the Resolution [56] adopted at the third UN Environment Assembly in December 2017 (presided by Costa Rica's environment minister H.E. Edgar Gutiérrez) to prevent and significantly reduce marine pollution of all kinds by 2025.

Public awareness of threats to the high seas from people's every-day choices is also increasing, thanks in part to high-impact broadcasts on mainstream media.[4] Locally in Costa Rica, Fundación MarViva has for the past two years coordinated a social media campaign – *#ChaoPlásticoDesechable* (Goodbye Disposable Plastic) – focused on generating awareness about the need to stop using disposable plastics (plastic bags, plastic straws, plastic bottles, etc.). This project is working with several municipalities trying to persuade them to pass legislation that would reduce the consumption of plastics. In Congress, Fundación MarViva is promoting a law to create a national fund for the oceans (FONASEMAR). The idea of the fund is that it would provide financing for relevant projects in the ocean, for example, by changing fishing gears for more responsible options, granting projects to coastal communities to improve their livelihoods, and reducing plastic consumption. This fund would be nurtured primarily by a tax levied on the importation of plastic (both finished products and raw materials), as well as from other sources.

As explained previously, the Dome is a persistent and predictable feature. Kahru et al. [49] recognise the Dome as being the pre-eminent location in the world where high nutrient and chlorophyll-a coupling results in outstanding primary productivity by picophytoplankton. The absence of larger groups of phytoplankton is due to the metal-trace limited environment, a characteristic of special areas known as High Nutrient Low Chlorophyll (HNLC). These regions are often related to upwelling systems, where there is a high injection of nutrients from subsurface waters but resources cannot be fully utilised because of micronutrient limitations, mainly iron. This brings special attention to the Dome as a potential candidate for future ocean fertilisation experiments.

HNLC zones around the world are being studied to explore their potential as possible locations of extended fertilisation efforts. Ocean fertilisation envisages introducing large quantities of iron compounds into the ocean to stimulate the growth of phytoplankton, mainly for the augmented sequestration of carbon dioxide from the atmosphere. In addition, ocean fertilisation has been advocated as a way to enhance fisheries, by boosting the primary production and thus gaining biomass that can be consumed by commercially important fish [50]. Although interesting conceptually, ocean fertilisation has been subject of controversy and debate due to the uncertainty about long-term effects on ocean dynamics and consequences to the ecosystem balance. In 2008, Parties at CBD COP-9 in Decision IX/16 "noting the 2007 Statement of Concern of the London Convention and Protocol, urged Parties and other Governments to act in accordance with the decision of the London Convention, that recognised the current absence of reliable data covering all relevant aspects of ocean fertilisation, without which there is an inadequate basis on which to assess their potential risks, and put into place what is now known as the CBD moratorium" [51,52]. On this basis and to ensure sustainable use of resources, there is a need for any new regime in ABNJ to apply a precautionary approach for locations such as the Dome, and to properly evaluate risks (EIA/SEA requirements). The new legally binding Implementing Agreement to UNCLOS must therefore also be well articulated with the London Convention.

4. Conclusion: future-proofing the Dome

Large offshore pelagic features such as the Dome are worthy of extra consideration and enhanced efforts to maintain their healthy functioning. This is a long-term commitment. It is important to recognise the significance of such locations and address both known issues (i.e., need for improved fisheries management) and predict future issues (e.g., potential ocean fertilisation schemes). From this study it is clear that complex pelagic features such as the Dome are often poorly understood. The bottom-up coupling of the planktonic trophic dynamics makes deeper comprehension of the Dome's pelagic ecology at a mesoscale a clear priority for future research. Pelagic features are also likely very difficult to restore if their ecological balance is upset and the timescale to restore such ecosystems will be considerable if not impossible. The impact and consequences of 'plastic soup' in offshore environments also needs further research – causes for concern include cumulative impact, health implications into the food chain, magnification of pollutants, impaired ecosystem components and stress to threatened and endangered species. Sources, pathways and potential harm caused by microplastics all need more research [53].

In terms of future-proofing the Dome, conservation and sustainable use of marine biodiversity in ABNJ is recognised as a governance gap. This strengthens the case for exceptional locations in ABNJ such as the Dome to be considered for World Heritage status. In addition, the issues highlighted here reinforce the need for a functioning Regional Seas Convention for the east tropical Pacific Ocean. Regional Seas Conventions have been active in tackling pollutants including marine debris through developing regional action plans. The second session of the United Nations Environment Assembly of the United Nations Environment Programme (UNEP/EA.2/Res. 10, §12 and 13) invited "Member States that have not done so to consider becoming parties to and/or members of Regional Seas Conventions and Action Plans" and encouraged "Contracting Parties to existing Regional Seas Conventions to consider the possibility of increasing the regional coverage of those instruments in accordance with international law". The Antigua Convention, signed in 2002 by Panama, Costa Rica, El Salvador, Honduras, Guatemala and Nicaragua, is an expression of political will, but the Convention needs at least four country ratifications to come into force and only two countries (Guatemala and Panama) have ratified it thus far. In Costa Rica, inter-ministerial coordination is working to present the Convention to Congress for approval. Fundación MarViva is working with UN Environment to promote and encourage ratification in collaboration with the Convention Secretariat (Guatemala). A key recommendation from this work is to support regional solutions in the context of current ABNJ negotiations, as the latter are unlikely to be concluded any time soon and conservation needs are urgent.

[4] BBC Blue Planet II television documentary series (http://www.bbc.co.uk/programmes/p04tjbtx).

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References

[1] F. Douvere, World Heritage Marine Sites: managing effectively the world's most iconic marine protected areas. Best Practice Guide, UNESCO-WHC, Paris, France, 2015⟨http://whc.unesco.org/document/137595⟩ (accessed 21 November 2017).
[2] R. Casier, F. Douvere (Eds.), The future of the world heritage convention for marine conservation: celebrating 10 years of the World Heritage Marine Programme, UNESCO, Paris, France, 2016, ⟨http://unesdoc.unesco.org/images/0024/002468/246839e.pdf⟩ (accessed 21 November 2017).
[3] M.D. Spalding, V.N. Agostini, J. Rice, S.M. Grant, Pelagic provinces of the world: a biogeographic classification of the world's surface pelagic waters, Ocean Coast. Manag. 60 (2012) 19–30, http://dx.doi.org/10.1016/j.oceanman.2011.12.016.
[4] A. Abdulla, D. Obura, B. Bertzky, Y. Shi, Marine World Heritage: creating a globally more balanced and representative list, Aquat. Conserv.: Mar. Freshw. Ecosyst. 24 (S2) (2014) 59–74, http://dx.doi.org/10.1002/aqc.2527.
[5] D. Freestone, D. Laffoley, F. Douvere, T. Badman, World Heritage in the High Seas: an idea whose time has come, UNESCO, Paris, France, 2016⟨http://unesdoc.unesco.org/images/0024/002454/245467e.pdf⟩ (accessed 21 November 2017).
[6] D.K. Briscoe, S.M. Maxwell, R. Kudela, L.B. Crowder, D. Croll, Are we missing important areas in pelagic marine conservation? Redefining conservation hotspots in the ocean, Endanger. Species Res. 29 (2016) 229–237, http://dx.doi.org/10.3354/esr00710.
[7] P.J. Auster, K. Gjerde, E. Heupel, L. Watling, A. Grehan, A.D. Rogers, Definition and detection of vulnerable marine ecosystems on the high seas: problems with the "move-on" rule, ICES J. Mar. Sci. 68 (2) (2010) 254–264, http://dx.doi.org/10.1093/icesjms/fsq074.
[8] R. Sharma, Deep-sea mining: current status and future considerations, in: R. Sharma (Ed.), Deep-Sea Mining, Springer, Cham, 2017, pp. 3–21, , http://dx.doi.org/10.1007/978-3-319-52557-0_1.
[9] J. Barberan, A. Gallegos, A.R. Padilla, The Costa Rica Dome during the onset of the 1982-83 El Niño, Trop. Ocean-Atmosphere Newsl. 24 (1984) 13–14.
[10] K. Wyrtki, Upwelling in the Costa Rica Dome, Fish. Bull. 3 (1964) 355–372 ⟨https://www.st.nmfs.noaa.gov/spo/FishBull/63-2/wyrtki.pdf⟩ (accessed 21 November 2017).
[11] C.L. Brenes, J.E. Coen, Correlación T-S de las masas de agua en la región del domo térmico de Costa Rica, Uniciencia 2 (1) (1985) 41–50.
[12] D. Ballestero, J.E. Coen, Generation and propagation of anticyclonic rings in the Gulf of Papagayo, Int. J. Remote Sens. 25 (11) (2004) 2217–2224, http://dx.doi.org/10.1080/01431160310001642395.
[13] M. Blackburn, Micronekton of the eastern tropical Pacific Ocean: family composition, distribution, abundance and relation to tuna, Fish. Bull. 67 (1) (1968) 71–115 ⟨https://www.st.nmfs.noaa.gov/spo/FishBull/67-1/blackburn.pdf⟩ (accessed 21 November 2017).
[14] J. Ardron, N. Ban, N. Bax, P. Bernal, S. Bograd, C. Corrigan, P. Dunstan, et al., D.C. Dunn (Ed.), Ecologically or Biologically Significant Areas in the Pelagic realm: Examples and Guidelines – Workshop report, IUCN, Gland, Switzerland, 2011, p. 44 ⟨https://portals.iucn.org/library/sites/library/files/documents/2011-055.pdf⟩ (accessed 21 November 2017).
[15] P.C. Fiedler, The annual cycle and biological effects of the Costa Rica Dome, Deep Sea Res. Part I: Oceanogr. Res. Pap. 49 (2) (2002) 321–338, http://dx.doi.org/10.1016/S0967-0637(01)00057-7.
[16] D.M. Palacios, S.J. Bognal, D.G. Foley, F.B. Schwing, Oceanographic characteristics of biological hot spots in the North Pacific: a remote sensing perspective, Deep Sea Res. Part II: Top. Stud. Oceanogr. 53 (3–4) (2006) 250–269, http://dx.doi.org/10.1016/j.dsr2.2006.03.004.
[17] CBD, Report of the Eastern Tropical and Temperate Pacific Region Workshop to Facilitate the Description of Ecologically or Biologically Significant Areas. UNEP/CBD/RW/EBSA/ETTP/1/4, Galapagos Islands, Ecuador, 28-31 August 2012. ⟨https://www.cbd.int/doc/meetings/mar/ebsa-ettp-01/official/ebsa-ettp-01-04-en.pdf⟩ (accessed 21 November 2017), 2013.
[18] P.C. Fiedler, J.V. Redfern, L.T. Balance, Oceanography and Cetaceans of the Costa Rica Dome region, NOAA Technical Memorandum NMFS-SWFSC-590, 2017, p. 35, http://dx.doi.org/10.7289/V5/TM-SWFSC-590.
[19] FAO. The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome. 200pp. < ⟨http://www.fao.org/3/a-i5555e.pdf⟩ > (accessed 21 November 2017).
[20] H.A. Leslie, M.D. van der Meulen, F.M. Kleissen, A.D. Vethaak. Microplastic Litter in the Dutch Marine Environment: providing facts and analysis for Dutch policymakers concerned with marine microplastic litter. Final Report. Deltares-IVM, 104pp. ⟨https://science.vu.nl/en/Images/Deltares-IVM_rapport_microplastics-2_tcm296-409861.pdf⟩ (accessed 21 November 2017).
[21] V. Nielsen Muñoz, M.A. Quesada Alpízar (Eds.), Technical report: coastal marine environments of Costa Rica, Comisión Interdisciplinaria Marino Costera de la Zona Económica Exclusiva de Costa Rica, 2006, p. 221 ⟨http://www.kerwa.ucr.ac.cr/bitstream/handle/10669/11216/Infome_Tecnico_Ambientes_Marinos_Costa%20Rica_2006.pdf?sequence=1&isAllowed=y⟩ (accessed 21 November 2017).
[22] F. Douvere, Operational guidelines for the Implementation of the World Heritage Convention, World Heritage Centre, UNESCO, Paris, France, 2017⟨http://whc.unesco.org/document/163852⟩ (accessed 21 November 2017).
[23] GESAMP, Sources, fate and effects of microplastics in the marine environment: a global assessment, in: P.J. Kershaw (Ed.), *Reports and Studies* 90, IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, 2015, http://dx.doi.org/10.13140/RG.2.1.3803.7925.
[24] G.F. McEwen, M.W. Johnson, T.R. Folsom, A statistical analysis of the performance of the Folsom plankton sample splitter, based upon test observations, Arch. für Meteorol., Geophys. und Bioklimatol. A 7 (1954) 502–527, http://dx.doi.org/10.1007/BF02277939.
[25] R.C. Thompson, Y. Olsen, R.P. Mitchell, A. Davis, S.J. Rowland, A.W. John, D. McGonigle, A.E. Russell, Lost at sea: where is all the plastic? (838), Science 304 (2004) 838, http://dx.doi.org/10.1126/science.1094559.
[26] A. Gallagher, A. Rees, R. Rowe, J. Stevens, P. Wright, Microplastics in the Solent estuarine complex, UK: an initial assessment, Mar. Pollut. Bull. 102 (2) (2016) 243–249, http://dx.doi.org/10.1016/j.marpolbul.2015.04.002.
[27] D.C. Dunn, J. Ardron, N. Bax, P. Bernal, J. Cleary, I. Cresswell, B. Donnelly, P. Dunstan, et al., The convention on biological Diversity's ecologically or biologically significant areas: origins, development, and current status, Mar. Policy 49 (2014) 137–145, http://dx.doi.org/10.1016/j.marpol.2013.12.002.
[28] N.J. Bax, J. Cleary, B. Donnelly, D.C. Dunn, P.K. Dunstan, M. Fuller, P.N. Halpin, Results of efforts by the Convention on Biological Diversity to describe ecologically or biologically significant marine areas, Conserv. Biol. 30 (2016) 571–581, http://dx.doi.org/10.1111/cobi.12649.
[29] D. Johnson, C. Barrio Froján, P. Turner, P. Weaver, V. Gunn, D. Dunn, P. Halpin, N. Bax, P. Dunstan, Reviewing the EBSA process: improving on success, Mar. Policy 88 (2018) 75–85, http://dx.doi.org/10.1016/j.marpol.2017.11.014.
[30] J.A. Jiménez, The Thermal Dome of Costa Rica: an oasis of productivity off the Pacific coast of Central America, MarViva Foundation, San José, Costa Rica, 2017, p. 106 ⟨http://marviva.net/sites/default/files/documentos/el_domo_termico_de_cr_ingles_web_.pdf⟩ (accessed 21 November 2017).
[31] G.L. Shillinger, A.M. Swithenbank, H. Bailey, S.J. Bograd, M.R. Castelton, B.P. Wallace, J.R. Spotila, F.V. Paladino, et al., Vertical and horizontal habitat preferences of leatherback turtle post-nesting habitats in the South Pacific Ocean, Mar. Ecol. Progress. Ser. 422 (2011) 275–289, http://dx.doi.org/10.3354/meps08884.
[32] I. Zanella, A. López, Analysis of the biological resources in the marine sector of the Guanacaste Conservation Area (GCA). Technical report to inform the GCA management plan, Onca Natural S.A., 2012, p. 39 (accessed 21 November 2017), ⟨http://copa.acguanacaste.ac.cr:8080/bitstream/handle/11606/270/ACG%20An%C3%A1lisis%20Recursos%20Biol%C3%B3gicos%20AMP%20Andr%C3%A9s%20e%20Ilena.pdf?sequence=2&isAllowed=y⟩.
[33] M.A. Saito, G. Rocap, J.W. Moffett, Production of cobalt binding ligands in a *Synechococcus* feature at the Costa Rica upwelling dome, Limnol. Oceanogr. 50 (1) (2005) 279–290, http://dx.doi.org/10.4319/lo.2005.50.1.0279.
[34] M. Décima, M.R. Landry, M.R. Stukel, L. Lopez-Lopez, J.W. Krause, Mesozooplankton biomass and grazing in the Costa Rica Dome: amplifying variability through the plankton food web, J. Plankton Res. 38 (2) (2015) 317–330, http://dx.doi.org/10.1093/plankt/fbv091.
[35] K.M. Gjerde, L.L. Nordtvedt Reeve, H. Harden-Davies, J. Ardron, R. Dolan, C. Durussel, S. Earle, J.A. Jimenez, et al., Protecting Earth's last conservation frontier: scientific, management and legal priorities for MPAs beyond national boundaries, Aquat. Conserv. Mar. Freshw. Ecosyst. 26 (S2) (2016) 45–60, http://dx.doi.org/10.1002/aqc.2646.
[36] E. Bigagli, The EU legal framework for the management of marine complex social-ecological systems, Mar. Policy 54 (2015) 44–51, http://dx.doi.org/10.1016/j.marpol.2014.11.025.
[37] M. Dickey-Collas, A. McQuatters-Gollop, E. Bresnan, A.C. Kraberg, J.P. Manderson, R.D.M. Nash, S.A. Otto, A.F. Sell, et al., Pelagic habitat: exploring the concept of good environmental status, ICES J. Mar. Sci. 74 (9) (2017) 2333–2341, http://dx.doi.org/10.1093/icesjms/fsx158.
[38] A.J. Jamieson, T. Malkocs, S.B. Piertney, T. Fujii, Z. Zhang, Bioaccumulation of persistent organic pollutants in the deepest ocean fauna (Article 0051), Nat. Ecol. Evol. 1 (2017), http://dx.doi.org/10.1038/s41559-016-0051.
[39] M.A. Urrère, G.A. Knauer, Zooplankton fecal pellet fluxes and vertical transport of particulate organic material in the pelagic environment, J. Plankton Res. 3 (3) (1981) 369–387, http://dx.doi.org/10.1093/plankt/3.3.369.
[40] L.C.M. Lebreton, J. van der Zwet, J.-W. Damsteeg, B. Slat, A. Andrady, J. Reisser, River plastic emissions to the world's oceans, Nat. Commun. 8 (2017) 1–10, http://dx.doi.org/10.1038/ncomms15611.

[41] M. Cole, P. Lindeque, C. Halsband, T.S. Galloway, Microplastics as contaminants in the marine environment: a review, Mar. Pollut. Bull. 62 (2011) 2588–2597, http://dx.doi.org/10.1016/j.marpolbul.2011.09.025.
[42] E.M. Duncan, Z.L.R. Botterell, A.C. Broderick, T.S. Galloway, P.K. Lindeque, A. Nuno, B.J. Godley, A global review of marine turtle entanglement in anthropogenic debris: a baseline for further action, Endanger. Species Res. 34 (2017) 431–448, http://dx.doi.org/10.3354/esr00865.
[43] C.J. Moore, S.L. Moore, M.K. Leecaster, S.B.A. Weisberg, A comparison of plastic and plankton in the North Pacific central gyre, Mar. Pollut. Bull. 42 (2001) 1297–1300, http://dx.doi.org/10.1016/S0025-326X(01)00114-X.
[44] A.L. Lusher, G. Hernandez-Milian, J. O'Brien, S. Berrow, I. O'Connor, R. Officer, Microplastic and macroplastic ingestion by a deep diving, oceanic cetacean: the True's beaked whale *Mesoplodon mirus*, Environ. Pollut. 199 (2015) 185–191, http://dx.doi.org/10.1016/j.envpol.2015.01.023.
[45] T. Romeo, B. Pietro, C. Pedà, P. Consoli, F. Andaloro, M.C. Fossi, First evidence of presence of plastic debris in stomach of large pelagic fish in the Mediterranean Sea, Mar. Pollut. Bull. 95 (1) (2015) 358–361, http://dx.doi.org/10.1016/j.marpolbul.2015.04.048.
[46] S. Werner, A. Budziak, J. van Franeker, F. Galgani, G. Hanke, T. Maes, M. Matiddi, P. Nilsson et al. Harm caused by marine litter. MSFD GES TG Marine Litter – Thematic report. JRC Technical report EUR 28317 EN. http://dx.doi.org/10.2788/690366.
[47] S.L. Wright, R.C. Thompson, T.S. Galloway, The physical impacts of microplastics on marine organisms: a review, Environ. Pollut. 178 (2013) 483–492, http://dx.doi.org/10.1016/j.envpol.2013.02.031.
[48] A.L. Lusher, N.A. Welden, P. Sobral, M. Cole, Sampling, isolating and identifying microplastics ingested by fish and invertebrates, Anal. Methods 9 (2016) 1346–1360, http://dx.doi.org/10.1039/c6ay02415g.
[49] M. Kahru, P.C. Fiedler, S.T. Gille, M. Manzano, B.T. Mitchell, Sea level anomalies control phytoplankton biomass in the Costa Rica Dome area, Geophys. Res. Lett. 34 (22) (2007) 1–5, http://dx.doi.org/10.1029/2007GL031631.
[50] F.M.M. Morel, J.G. Reuter, N.M. Price, Iron nutrition of phytoplankton and its possible importance in the ecology of ocean regions with high nutrient and low biomass, Oceanography 4 (2) (1991) 56–61 ⟨https://tos.org/oceanography/assets/docs/4-2_morel.pdf⟩ (accessed 21 November 2017).
[51] CBD, Decision adopted by the Conference of the Parties to the Convention on Biological Diversity at its ninth meeting: IX/16 Biodiversity and climate change. UNEP/CBD/COP/DEC/IX/16, Bonn, 19-30 May 2008. ⟨https://www.cbd.int/doc/decisions/cop-09/cop-09-dec-16-en.pdf⟩ (accessed 21 November 2017), 2008.
[52] E.J. Duncan, L.L.B. Currie. A Brief Primer on Ocean Fertilization in the CBD and the London Convention and Protocol. Retrieved on 21 November 2017, from ⟨www.etcgroup.org/content/brief-primer-ocean-fertilization-cbd-and-london-convention-and-protocol⟩.
[53] LC&LP, Review of the current state of knowledge regarding marine litter in wastes dumped at sea under the London Convention and Protocol: final report, Office for the London Convention/Protocol and Ocean Affairs, International Maritime Organization, London, 2016, p. 35 ⟨http://www.imo.org/en/OurWork/Environment/LCLP/newandemergingissues/Documents/Marine%20litter%20review%20for%20publication%20April%202016_final_ebook_version.pdf⟩ (accessed 21 November 2017).
[54] L. Abarca-Guerrero, F. Roa-Gutiérrez, V. Rudín-Vega, WEEE Resource Management System in Costa Rica, Resources 7 (2) (2018) 1–14, http://dx.doi.org/10.3390/resources7010002.
[55] E. Gutiérrez, M.E. Anchía, A. Shackelford, Costa Rica paves the way to end single-use plastics, UNDP Website (2017), ⟨http://www.undp.org/content/undp/en/home/blog/2017/7/14/Costa-Rica-abre-el-camino-hacia-el-fin-de-los-pl-sticos-de-un-solo-uso.html⟩ (accessed 12 February 2018).
[56] UNEP/EA.3/L.20. United Nations Environment Assembly of the United Nations Environment Programme Resolution on Marine Litter and Microplastics. 5 December 2017, 4 pp. ⟨https://papersmart.unon.org/resolution/uploads/k1709154.docx⟩ (accessed 12 February 2018).