THE SKIMMER ON MARINE ECOSYSTEMS AND MANAGEMENT

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Artificial light may be changing marine ecosystems [1]

Editor's note: Artificial light at night (ALAN)– whose undesirable effects are more colloquially referred to as light pollution – has long been known to affect sea turtles. Numerous studies document that adult sea turtles avoid nesting on artificially-lit beaches [2] and artificial lights on land draw newly-hatched sea turtles away from the ocean [3], leading to increased mortality due to increased predation, dehydration and energy expenditure [2]. But what about other marine organisms? In this article, we explore (Skimmer-style) recent research about how light pollution may be affecting many marine organisms and ultimately marine ecosystems.

Natural light cues structure a lot of behaviors and processes in marine ecosystems

- Most marine organisms in the surface ocean (from surface to 200 m depth) are adapted to natural light from the sun, moon, and stars [4]. Cues from natural light – including its cycles, colors, intensities, and spatial orientation [4] – help structure many organismal behaviors and ecological processes in marine ecosystems.
    - These behaviors and processes include migrations (e.g., lunar compasses for long distance migration [5], daily vertical migrations cued by moonlight [6]), foraging [7], predation [7], rest, and reproduction (e.g., timing of broadcast spawning [8]) for marine reptiles [7], amphibians [7], fish [7], birds [7], mammals [7], and invertebrates [7].
    - In addition to light being a source of information [3], light is also a resource for photosynthesis and primary production [3].
- Artificial light at night (ALAN) interferes with natural light patterns and the biological processes they help control [4] and can dramatically affect the behavior of marine organisms [8], species interactions [7], distributions of marine organisms [8], and food webs [8] and can potentially restructure coastal marine ecosystems [4].

Coastal light pollution is global and getting worse

- ALAN in marine environments comes from coastal development [4] (e.g., buildings, streetlights, billboards, ports, piers, docks [4]) as well as vessels (e.g., fishing and merchant marine vessels) and offshore infrastructure such as oil rigs. It has increased exponentially over the past 150 years [7] and has become a significant issue for the marine environment in the last 60-90 years [7].
- Artificial skyglow is one of the most common forms of ALAN. It refers to the diffuse luminance of the night sky from artificial lighting [9] – both upward-directed light as well as light reflected from the ground or water or other surfaces [9]. Artificial skyglow often forms a dome of light over cities and towns [9] and is visible from great distances [9].
    - Artificial skyglow can now be detected above 22 percent of the world's coasts nightly [4] – with Europe, Asia and Africa having the highest percentages of their coastlines affected [10]. Coastal populations are expected to double by 2060 [4], with an attendant increase in coastal ALAN intensity and spread [11].
    - A recent global mapping effort (2020) found the coastal areas most threatened by ALAN to be in the Red Sea, the Persian Gulf, the eastern Caribbean, and the western Pacific regions [12]. In the Gulf of Aqaba/Eilat, some areas are 60 times brighter than under a natural night sky [13], and even relatively unaffected areas of the gulfs are nearly 50 percent brighter [13].
- Another recent study (2020) examined the extent to which artificial light from coastal cities reaches the nearby seafloor [5]. Researchers shined artificial lights that mimicked city skyglow and measured exposure [5] at the surface of the water column, in the water column, and on the seafloor of a local estuary. They found that on cloudy nights (which have more light reflected back to the ground than clear nights [6]) green and blue wavelengths of light-emitting diode (LED) light reach 70 percent or more of the three-dimensional space around seafloor habitats [5] whereas less than 1 percent of the seafloor is exposed to "biologically important" levels of red wavelengths [5]. In addition since estuaries generally have higher levels of sediment and less light penetration than many other coastal habitats, researchers estimate that ALAN could reach 100 percent of the seabed [6] in clearer coral reef systems. These findings suggest that marine habitats near all coastal cities could be exposed to ALAN.
- Light pollution in marine environments in also becoming more severe due to the increasing prevalence of LED lights. LEDs now account for roughly half of global light sources [14], and that share is expected to grow to nearly 90 percent of global light sources by 2030 [14]. White LEDs produce broad spectrum light that is sensed by a wide range of organisms [3] and have a peak at short wavelengths (blue and green light) to which many marine organisms are particularly sensitive. [15] Moreover, these shorter wavelengths penetrate deeper into the water column [6], affecting organisms at greater depths.

Artificial light at night (ALAN) interferes with marine ecosystem processes

A conceptual map of individual- to ecosystem-level responses to ALAN

A conceptual map of individual- to ecosystem-level responses to ALAN in estuarine ecosystems by Zapata et al. (2019) [3] classifies responses by level of organization.

- At the **individual** level, ALAN can impact **physiology and behavior by increasing, decreasing, and/or altering diel and nocturnal activity**
  - Mechanisms for this occurring can include changes to visual sensitivity, circadian rhythms, predation risk, food availability, and stress and reproductive hormone levels.
- At the **population** level, ALAN can impact **performance by shifting diel or nocturnal activity which may enhance or reduce fitness**
  - Mechanisms for this occurring can include lit areas serving as polarized or direct light traps or light expanding or constraining activity intervals.
- At the **species** level, ALAN can impact **interactions by altering predation and competition among diurnal and nocturnal taxa**
  - Mechanisms for this occurring include changes to the spatial, spectral, and temporal composition of light and the spatiotemporal distribution of food resources and habitat.
- At the **community** level, ALAN can impact **composition by changing relative abundance, species diversity, and distribution of taxa**
  - Mechanisms for this occurring include changes to the availability and partitioning of resources, risk regimes, and movement and dispersal patterns.
- At the **food web** level, ALAN can impact **structure by restructuring trophic network topology and functional attributes**
  - Mechanisms for this occurring include altering interaction strengths via spatial and temporal shifts and changing aquatic primary productivity.
- At the **ecosystem** level, ALAN can impact **function by changing nutrient cycling, biodiversity, and ecosystem productivity**.
  - Mechanisms for this occurring include changes to cross-boundary nutrient flows.
- Changes at any of these levels of organization (e.g., individual, population, species, community, food web, and ecosystem) can in turn impact other levels of organization [3] (e.g., individual responses can cause population and community level impacts).

Text from Zapata, M.J., Sullivan, S.M.P. and Gray, S.M. Artificial lighting at night in estuaries – Implications from individuals to ecosystems. Estuaries and Coasts 42, 309–330 (2019). https://doi.org/10.1007/s12237-018-0479-3 [16]

- There has been relatively little study of the impacts of ALAN on marine organisms and environments to date [3], but evidence of impacts is starting to emerge.
- There is now growing evidence that ALAN causes stress responses and changes activity levels, metabolic processes, and circadian rhythms in marine organisms.
  - A seminal work on light pollution in a freshwater lake (2000) found that urban light pollution reduced the amplitude of zooplankton diel vertical migration [17] as well as the number of individuals migrating [17]. Since nearly a third of global ocean primary production takes place in the coastal ocean [15] and zooplankton diel vertical migration is a major pathway in the ocean carbon cycle [18], ALAN could be altering ocean carbon and nutrient cycling [15].
  - Another early study (2007) found that post-smolt Atlantic salmon exposed to high intensity blue LED lights showed an acute stress response (increase in cortisol levels) which subsided by 24 hours after the light exposure started [19]. Elevated levels of cortisol over a long period can compromise immune response and affect metabolism [3].
  - In a study from 2015, Atlantic salmon fry exposed to broad spectrum light equivalent to that of street lighting dispersed later in development (mean delay of 1.4-2.3 days) and later in the day (mean delay of 1.5 hours later after dusk with a significant percentage not dispersing until daylight hours) than fry under normal light-dark cycling [20]. The later dispersal (both in terms of days and time of day) may reduce fitness of the smolts due to decreased feeding opportunities and/or increased predation [3].
  - A study from 2019 found that, when exposed to ALAN, two coral species from the Gulf of Eilat/Aqaba in the Red Sea had higher rates of free radicals [21]. Free radicals are chemically reactive forms of oxygen [21] that can damage an organism's proteins and DNA [21]. Researchers also found that the corals' symbiotic algae experienced population fluctuations and reduced photosynthesis [22] under ALAN and that blue and white LED lights had a greater effect on the coral and algae than yellow LED light [22].
  - Another study from 2019 found that when juvenile conch, a keystone species along southeastern Pacific coasts including the Chilean coast, were exposed to LED light, their metabolisms and the time they took to right themselves increased [23]. They also hunted more efficiently in darkened habitats [23] than when exposed to artificial light.
  - And another study from 2019 found that rockfish, an abundant and ecologically important intertidal fish in the southeastern Pacific, increased their activity and oxygen consumption [24] and stopped displaying their natural circatidal and circadian activity cycles [24] when exposed to artificial light of the same intensity to which local fish are exposed.
  - One of the few studies (2019) of the effects of ALAN on sandy beach ecosystems [25] looked at common isopods on sandy beaches in north-central Chile. These isopods burrow in the sand during the day and migrate closer to the water at night. In the laboratory, isopods exposed to ALAN reduced their movements [25] and lost their circadian rhythm [25] relative to controls with a natural day/night cycle. In field experiments, isopod numbers were clearly lower under artificial light that mimicked public lighting [25] relative to control transects.
  - And in the first study to look at the impacts of ALAN on marine fish larvae [26] (2019), researchers found that coral reef fish larvae grew faster and heavier [26], exhibited different swimming behaviors [26], and experienced greater predation at night [26] under ALAN. Mortality was higher for larvae exposed to ALAN than larvae under control conditions [26] by the end of the 10-day experiment. Researchers also found that coral reef fish larvae avoided settling in artificially lit habitats [26].
- Other studies have also found evidence of changes to species distributions and interactions, particularly predator-prey interactions, due to ALAN. Among other influences, ALAN can function as a light trap concentrating prey species, make it easier for predators to see prey at night [10], and reduce natural camouflaging of prey species [10].
  - An early study published in 2000 found intense predation on juvenile Pacific salmon by seals under two brightly lit bridges in British Columbia [27]. When the lights were turned off, the number of seals under the bridges initially decreased [27] but eventually returned to prior levels as the seals seemed to learn to use the residual city lighting for their feeding [27].
  - A 2013 study of the impact of a 400-W sodium vapor floodlight on lit areas in a South African estuary [28] found an increase in small shoaling fish in the lit areas [28] (likely due to attraction to the light) as well an increase in large predatory fish [28] (likely due to concentration of prey and enhanced visual predation capabilities). In turn, the lit area is a popular fishing spot for humans [28]. These results suggest that artificial lighting has the potential to alter estuarine communities by creating optimal conditions for predators [28].
  - In a 2017 study, researchers placed LED spotlights under a wharf in an Australian harbor [29]. Fewer fish utilized the areas at night relative to unlit control periods

[29], but despite the decreased usage, predation on sessile invertebrate prey assemblages increased [29] in the lit areas relative to unlit periods. These results suggest that some fish lost a nighttime refuge where they could rest and decrease their energy usage [29] and some fish utilized the artificial light to increase feeding [29].

- There is also increasing evidence that ALAN impacts how sessile invertebrates select settlement sites and their subsequent survival rates. Many sessile invertebrates such as corals, bryozoa, polychaetes, tunicates, and barnacles are ecosystem engineers that create habitats for other organisms [30], and their settlement locations and survival and reproductive rates help determine community composition and function [10] as well as ecosystem functioning (including controlling the depth at which photosynthesis can occur [30]).
    - A 2015 study found that artificial light similar to that of streetlights (on the higher end of artificial light conditions in marine environments) led to changes in the composition of epifaunal marine invertebrate communities [31] in the Menai Strait in the UK. Researchers observed changes in colonization rates for 39% of the taxa observed [32]. Specifically, they found lower colonization rates on substrates by sea squirts and higher colonization rates by a range of species considered nuisance fouling species such as barnacles [33]. Barnacle fouling is estimated to cost the global economy over US$300M annually, and this study raises the intriguing possibility that changes to ambient lighting around ships and ports could help address this issue [32].
    - In another 2015 study, traps set in shallow waters of the Great Barrier Reef under artificial light conditions caught more individuals for all species than traps in natural light conditions [34]. For amphipods, the species assemblages caught under LED lights were different [34], suggesting that some amphipod species are specifically attracted to LED light [34].
- In addition to the findings that ALAN can cause stress responses in corals [21], increase larval mortality of coral reef fish [26], and discourage settlement of coral reef fish larvae [26], there is evidence that ALAN may impact coral reef ecosystems in other ways.
    - In a 2020 study, ALAN led to unsynchronized spawning [12] in two coral species from the Indo-Pacific Ocean, and ALAN is currently hypothesized to be one of the main drivers for the lack of synchronization in spawning for three of five coral species in the Red Sea [35], one of the most light polluted coastal regions in the world [12]. Synchronization of broadcast spawning events helps ensure successful fertilization [10], and interference with this timing may lead to declines in recruitment [10].
    - In a year-long laboratory study (2020), settlement and photosynthetic efficiency of a Red Sea coral were lower under fluorescent and LED lights than under control conditions [36], but coral survivorship, growth, and calcification were higher under artificial light conditions [36].

Furthering ALAN research in marine ecosystems

- Minimizing ALAN and its attendant impacts on marine ecosystems will require a great deal more research, management, and policy making. Some suggestions from the literature for furthering ALAN research include:
    - Considering light intensity, exposure cycles, spectra, and directionality [32] as well as differential effects on individuals (e.g., different life stages) and species when studying the effects of ALAN on marine organisms and ecosystems.
    - Increasing the temporal and spatial resolution of ALAN monitoring, including more widespread sensing at the ocean surface and in the water column.
        - Satellites detect light emitted upward under clear sky conditions [10] but don't provide a thorough understanding of conditions below the sea surface [37]. In the water column, organisms are exposed to direct or scattered light and light reflected back from atmosphere [10], and different wavelengths attenuate at different depths.
        - In addition, the lack of spatial resolution of satellite measurements of ALAN makes it difficult to detect impacts on marine populations [15]. Strategic "ground-based sensing" at the ocean surface and in the water column could fill this gap.
        - Some opportunistic ways to add resolution to ALAN monitoring include mounting sensors on coastal and offshore infrastructure such as oil platforms, ships of opportunity, and Global Ocean Observing System buoys [10]. Predictive models can also help flesh out ALAN dynamics in time and space [10].
    - Targeting research to species and ecosystems which provide obvious and documented ecosystem services [10] so that the economic impacts of changes in ecosystem structure and function [10] can be considered in policymaking.

- In addition, existing ALAN research suggests that oceanographic research in general needs to assess and potentially adjust lighting on biological sampling platforms like research vessels [38] to avoid corrupting the biological data collected. This is especially critical for research conducted in low-light conditions such as the Arctic polar winter [39] and the deep ocean where organisms are adapted to extremely low light levels.
  - For instance, in the deep ocean, the natural light available is very dim, monochromatic, and downward directed [7] or comes from the bioluminescence of marine organisms [7]. Consequently, most deep sea organisms have highly specialized visual systems sensitive to extremely low light levels [7] that may be damaged by the bright lights of submersible vehicles [7] used for exploration and research.
  - And during the polar winter in the Arctic, all natural light comes from the moon, stars, and aurora borealis. In a study published in 2018, researchers studied the behavior of fish and zooplankton in an un-light-polluted environment [38] in the high Arctic during the polar winter and compared it to behaviors close to their research vessel to see what impact the ships' lights might have. They found that when the ship's light turned on, fish and zooplankton changed their vertical positions and swimming behavior quickly (within five seconds [39]) and that the ship's light affected the behavior of organisms as deep as 200 m and in an area 125 m^2 around the ship [39]. These results suggest that ships' light may influence the results of ship-based biological research and assessments of both commercial and non-commercial marine stocks [39].
- New initiatives are now forming to improve and standardize ALAN research. In January 2020, a new international network GLOW (Global artificial Light Ocean netWork) [40] formed to study the potential effects of ALAN on "coastal assemblages colonizing artificial structures". GLOW will survey the intensity and quality of ALAN and its effect on intertidal algae and invertebrates [40].

Furthering ALAN policy for marine ecosystems

- The only marine areas currently managed for ALAN are some sea turtle nesting beaches where broad-spectrum lights have been replaced [3] with longer wavelength lights to reduce hatchling mortality. In the future, consideration of ALAN – particularly its intensity and spectra – needs to be embedded in all coastal and marine development and use decisions [7]. To reduce ALAN that is harmful to marine (and freshwater and terrestrial) environments, individuals and groups developing and using coastal and marine areas can reduce excess lighting [5] by:
  - Reducing the number of lights [6], light intensity [6], and the time that lights are on [3]. Reducing artificial light at dawn and dusk [3] may be especially beneficial to marine environments because of the numerous biological processes that are focused on these time periods.
  - Installing limited-angle lights [3] or shielding lights to prevent light spilling into unwanted areas [41].
  - Installing motion-sensitive lights [3] in areas where lighting may be needed for safety.
  - Using LED bulbs that emit less blue and green (shorter wavelength) light. Red (longer wavelength) light attenuates faster in water [42] and is not detected as easily by marine organisms [6].
- There is currently a dearth of legal and regulatory tools [43] for minimizing the impact of ALAN on marine environments and ecosystems. As these tools are developed (e.g., it has been suggested that MARPOL recognize artificial light as a pollutant [10]), ALAN researchers suggest incentivizing authorities to reduce ALAN by creating a "Marine Dark Sky Park" designation [43] for MPAs. In 2012, 35 percent of the world's MPAs were subject to ALAN [43], with 57 percent of those exposed to light across their entire domain [43] and 72 percent exposed to light across more than half of their domain [43].

Photo credit: Lights of Vancouver, British Columbia, Canada, as seen from Stanley Park by Seán Ó Domhnaill [44].

Latest News and Resources for Ocean Planners and Managers [45]

- Study shows few downsides to incorporating climate change in ocean planning [46]
- Researchers map ocean areas that can protect biodiversity, help fisheries, AND provide carbon benefits [47]
- Most ocean use revenues go to small number of corporations [48]
- New satellites will track global carbon and methane emissions [49]
- Climate change already making equator too warm for many marine species [50]
- In ~2025, lunar cycle will start accelerating sea level rise [51]
- Scientists using dynamic modeling to forecast marine heatwaves [52]
- Carbon emissions from bottom trawling similar to those of aviation industry [53]
- Special issue of Parks Journal on protected area and COVID-19 pandemic [54]
- Lack of thiamine disrupting some marine ecosystems [55]
- Darkening of coastal waters could alter ecosystems [56]
- Surface slicks provide critical nursery habitat for marine invertebrates and fish [57]
- IUCN reclassifies additional 39 shark and ray species as threatened [58]
- US NOAA launching model to predict rip currents up to six days in advance [59]
- Scotland's floating wind farm outperforming wind farms closer to shore [60]
- US approves first large-scale offshore wind project [61]; other major US projects in the works [62]
- Ocean data coalition launches "ocean avatar" for research and management [63]
- UN releases integrated assessment of global ocean environment, economy, society [64]
- Coral atlases for Central Indian Ocean, Great Barrier Reef, Torres Strait, Western Australia, Southeastern Asia, the Philippines, South China Sea available [65]

Some more fisheries-related news and resources:

- Seawater DNA analysis offers cheaper, quicker, noninvasive assessment of fish stocks [66]
- Satellites help determine extent of forced labor in world's fishing fleet [67]
- New toolkit helps managers and practitioners make good decisions for finfish aquaculture [68]
- New toolkit helps strengthen small-scale fishery governance [69]
- Environmental DNA in sea floor sediments can help chart fish populations over centuries [70]

Some more plastic pollution-related news and resources:

- Plastic consumption of marine fish doubled in last decade [71]
- Study suggests 1,000+ rivers - not just handful - sending significant plastic to ocean [72]
- Report documents "hidden" impacts of chemical and plastic pollution on marine life [73]
- New report examines environmental justice impacts of plastic pollution [74]
- Plastic industry project to clean up ocean waste fails to meet goals and shuts down [75]
- High levels of microplastics found in Antarctic/Southern Ocean deep sea sediments [76]
- Study suggests oceans may be launching microplastics into atmosphere [77]

Some more deep sea-related news and resources:

- Ecosystem and biodiversity risks of deep seabed mining outlined [78]
- Human immune systems do not detect many deep sea microbes [79]
- Three companies dominate deep sea exploration contracts with lax oversight [80]
- Biomimicking “soft” robot navigates Marianas Trench, shows future of deep sea exploration [81]
- Deep sea plastic provides habitat for benthic organisms [82]
- Deep sea trails provide strong evidence that adult sea sponges are motile [83]
- Deep waters in Southern Ocean warming fast, threaten Antarctica ice sheet [84]

And some other recent news articles that caught our attention:

- Report recommends aquaculture of seaweeds, bivalves to improve welfare, reduce risk [85]
- Animal welfare movement increasingly looking at treatment of fish in aquaculture [86]
- Video depicts dangers of shipping for blue whales [87]
- Climate change causing earth’s poles to shift more rapidly [88]
- Scientists get rare glimpse at ecosystems under Antarctic ice shelves [89]
- Ten remarkable marine species discovered in 2020 [90]

The EBM Toolbox: Resources for the sustainable financing of marine protected areas [91]

Editor’s notes: OCTO, the parent organization for The Skimmer and the EBM Tools Network, is currently working with the UN Environment Programme, the University of Queensland, The Nature Conservancy, WWF, and other partners to develop practical guidance on challenges in MPA practice, including effectiveness, sustainable financing, and climate change. Project partners recently surveyed marine conservation and management practitioners about tools and resources [92] that they would recommend to help with these challenges. In this EBM Toolbox, we present some preliminary results from this survey, specifically tools and resources to assist with MPA financing, including the related work of business planning and benefit sharing.

Do you know of other relevant tools or resources, particularly tools/resources to assist with equitable benefit sharing? Do you have experience using any of the resources or tools below? Please let us know about ebmtools@octogroup.org. For the next phase of our research, we will be updating these initial results and gathering input from practitioners about their experiences using these tools and resources.

Part A: Tools and guides for business planning and sustainable financing of marine protected areas

Catalog: BIOFIN Catalogue of Finance Solutions [93]
Provider: UNDP Biodiversity Finance Initiative
Description: This online catalog provides a comprehensive list of biodiversity finance instruments, tools, and strategies. Each catalog entry is a mechanism or “finance solution” and includes a brief description as well as links to guidance material or case studies.

Guide: Conservation Finance Guide (2002 with updates in 2019 and 2020) [94]
Provider: Conservation Finance Alliance
Description: This guide and associated documents provide guidance on business planning for protected areas and how to implement specific finance mechanisms in seven different classes. Specific finance mechanism include: biodiversity enterprise funds, biodiversity prospecting, carbon offset projects, debt-for-nature swaps, environmental funds, fiscal instruments, payments for watershed services, philanthropic foundations, bilateral and multilateral donors, extraction of non-renewable resources, tourism entrance and activity fees, tourism concessions in protected areas, and international public climate finance for biodiversity.
For more information:

- Watch two webinars on the associated white paper Conservation Finance: A Framework [95], which provides several frameworks to understand concepts associated with conservation finance and a taxonomy of conservation finance strategies and mechanisms (Webinar 1 [96] and Webinar 2 [97]).

Tool/Service: Eco2Fin (2015) [98]
Provider: Wolfs Company
Description: The Eco2Fin tool (proprietary to, and used in conjunction with, Wolfs Company) is a framework that uses an ecosystem services approach to identify sustainable finance mechanisms within the context of a protected area.
For more information:

- Use of Eco2Fin to analyze sustainable financing in Caribbean Islands is described here (short practice note) [99] and here (full report) [100].
- Read about use of Eco2Fin in Turks and Caicos Islands [101].

Guide: Finance Tools for Coral Reef Conservation: A Guide (2018) [102]
Provider: Wildlife Conservation Society and Conservation Finance Alliance, in support of the 50 Reefs initiative
Description: Aimed at protected area managers and others charged with managing and financing reef conservation, this guide provides descriptions of 13 types of finance tools that have proven successful at, or have good potential for, supporting reef conservation and sustainable management.
For more information:

- View a series of webinars on the finance tools covered in the guide including an overview webinar [103], a webinar on tourism-related tools [104], and a webinar on conservation trust funds and impact investing [105].

Assessment Tool: Financial Sustainability Scorecard: for National Systems of Protected Areas (2007) [106]
Provider: UN Development Programme
Description: This scorecard helps governments, donors, and NGOs investigate and record the structural foundations and accounts of their protected area financing system to assess its current health and status and long-term trends. The scorecard is designed for national systems of protected areas but can be used by state, regional, and municipal systems and MPA networks.

Guide: Financing mechanisms: A Guide for Mediterranean Marine Protected Areas (2021) [107]
Provider: BlueSeeds for the Co-managed No-Take Zones/MPAs project
Description: A continuation of the 2015 Sustainable financing of Marine Protected Areas in the Mediterranean: A guide for MPA managers (available here [108]), this new guide, designed for Mediterranean MPA managers, provides a step-by-step approach to help MPA managers accurately plan their financial strategy and implement relevant

and effective financing mechanisms adapted to their needs. While written for Mediterranean MPA managers, the mechanisms presented in the guide are useful and replicable globally.
For more information:

- Watch the launch webinar for the guide [109].
- In conjunction with the guide, BlueSeeds released a call in May 2021 for expressions of interest [110] to support Mediterranean MPAs in implementing visitor fees on their site. A call for expressions of interest for another mechanism presented in the guide will be launched later in 2021.
- BlueSeeds has also developed a new solution BlueMooring.org [111] to help global MPA managers manage their moorings and get sustainable revenues from them. A call for pilot and partner MPAs to adapt BlueMooring.org's functionality [111] was released in May 2021.

Guide: Guide pour l'élaboration des Plans d'Affaire simplifiés pour les Aires Protégées (2012) [112]
Provider: Benjamin Landreau (Lead author) for FIBA (Fondation Internationale du Banc d'Arguin; now MAVA), RAMPAO (Network of Marine Protected Areas of West Africa), FFEM (French Global Environment Fund), and AFD (French Development Agency)
Description: This French language guide provides MPA managers with a simple, step-by-step approach to independently develop a simple business plan. The guide is accompanied by simplified spreadsheets that managers can complete and update on a regular basis. It has a focus on African PAs but is applicable globally.

Overview: Marine Protected Areas: Economics, Management and Effective Policy Mixes – Chapter 4: Sustainable financing of marine protected areas (2017) [113]
Provider: OECD
Description: Book chapter that examines a range of financing instruments and approaches available for MPAs, ranging from traditional government budget and donor funding to user fees, taxes and fines, and payments for ecosystem services, among others.

Tool: MedPLAN (2015, updated 2020) [114]
Provider: MedPAN, SPA/RAC, WWF (Owners); Vertigo Lab, BlueSeeds (Developers)
Description: This freely-available business plan tool developed by Vertigo Lab and updated by BlueSeeds helps MPA managers build their business plan and financial strategy. It is a series of Microsoft Excel spreadsheets containing formulas that allow MPA mangers to build a business plan by reporting the financial data of their MPA. The tool assesses total annual costs for implementing the MPA management plan, present and future financial resources for the MPA, and the financing gap between estimated costs and financial resources. While developed for Mediterranean MPA managers, the tool is applicable globally.
For more information:

- Video tutorials for conducting this work are available on the MedPAN website [115].
- The tool can be freely downloaded here [116] or here [114].

Guide: Practice Standards for Conservation Trust Funds (2020) [117]
Provider: Conservation Finance Alliance
Description: These voluntary Practice Standards for Conservation Trust Funds serve as a tool for improving the design, management, and monitoring and evaluation of Conservation Trust Funds (CTFs).
For more information:

- See a range of Conservation Finance Alliance documents on CTFs [118].
- View a range of Conservation Finance Alliance webinars on CTFs [119], including:
    - Practice Standards For Conservation Trust Funds Webinar Series - Overview [120] (2021)
    - Practice Standards For Conservation Trust Funds Webinar Series - Programs And Monitoring & Evaluation [121] (2021)
    - Practice Standards For Conservation Trust Funds Webinar Series - Communications [122] (2021)
    - Practice Standards for Conservation Trust Funds Webinar Series - Resource Mobilization [123] (2021)
    - Seychelles' Conservation and Climate Adaptation Trust (SeyCCAT) with Angelique Pouponneau [124] (2020).

Guide: Protecting Our Marine Treasures: Sustainable Finance Options for U.S. Marine Protected Areas (2017) [125]
Provider: US Marine Protected Areas Federal Advisory Committee
Description: This report focuses on a wide range of approaches to obtain external funding for MPAs. It covers funding vehicles such as friends groups, foundations, fiscal sponsorships, and other non-profit organizations. In addition, it covers sources of external financing such as philanthropic giving, bonds, environmental mitigation activities, penalties and settlements, taxes, fees, corporate support, competitive grants, tourism-based support, and international partnerships.
For more information:

- Watch a webinar on the guide [126].

Tool: Reef Support [127]
Provider: Reef Support
Description: Reef Support is a simple, customizable, fee-based tool to help MPA managers collect and sell marine park fees to visitors. It offers a safe way to receive money and provides access to a database of park visitors, a ticketing system, and the possibility to generate customizable financial reports.
For more information:

- View a webinar on the tool [128].

Guide: Sustainable financing of Marine Protected Areas in the Mediterranean: A guide for MPA managers (2015) [108]
Provider: MedPAN, RAC/SPA, WWF (Publishers); Vertigo Lab (Technical Partner)
Description: This guide, designed for Mediterranean MPA managers, provides readers with information for developing the financial strategy of their MPA and identifying successful financing mechanisms. A continuation of this guide Financing mechanisms: A Guide for Mediterranean Marine Protected Areas (available here [107]) was published in 2021. While written for Mediterranean MPA managers, the mechanisms presented in the guide are useful and replicable globally.

Part B: Trainings and webinars for business planning and sustainable financing of marine protected areas

Training materials: Business planning for MPAs (2021) [115]
Provider: MedPAN, Brijuni National Park, and BlueSeeds
Description: As part of the MedPAN network training program, an online training session was held with nine Mediterranean MPAs in January-February 2021. This training alternated between five pre-recorded videos and individual meetings with each MPA to work on their specific case study. With the exception of the first Mediterranean context webinar, the video content is applicable to MPAs globally, and an equivalent training program is currently being developed for MPAs in Western Africa.
For more information:

- The teaching materials are freely available on the MedPAN website [115].

Training materials: Conservation Finance Training: Financing Sustainable Management of Marine and Coastal Biodiversity (2017)[129]
Provider: Blue Solutions
Description: Materials from this training course provide an introduction to the value of marine ecosystem services and the need for conservation finance to support marine and coastal management; opportunities and approaches for financing conservation of marine and coastal areas; and key features in establishing a conservation finance mechanism.
For more information:

- The live training will not be offered by Blue Solutions after 2021, but the training materials are freely available on the Blue Solutions website [129].

Webinar: Debt Conversions (2020) [130]
Provider: Conservation Finance Alliance
Description: This webinar discusses debt conversions (also known as debt for climate and nature swaps), a finance instrument that allows countries to reduce their national debt and reallocate funds for sustainable development and conservation projects.
For more information:

- See a previous Conservation Finance Alliance webinar about a US$40 million initiative to promote ocean conservation based on debt conversions in up to 20 countries [131].
- See a previous OCTO webinar on debt conversions for small island developing states, including an example from Seychelles [132].

Webinar: An introduction to business planning for protected areas (2017)[133]
Provider: Government of Seychelles-UNDP-GEF Protected Area Finance (project work), OCTO (webinar host)
Description: This webinar outlines the importance of business planning for protected areas and how business plans can be used as tools to leverage financial support for conservation management. The presentation also provides an introduction to the components of business plans and a collection of over 45 examples of protected area business plans and guidelines.
For more information:

- Read more about the project [134].
- View the collection of over 45 examples of terrestrial and marine protected area business plans from around the world [135].

Training: Sustainable Financing for Marine Protected Areas [136]
Provider: Coral Triangle Center
Description: This four-day course is an introduction to the concepts of sustainable financing and the range of tools and mechanisms available to support the long-term financing of MPAs.

Part C: Additional conservation financing resources

Report: Financing Nature: Closing the Global Biodiversity Financing Gap (2020)[137]
Provider: The Paulson Institute, The Nature Conservancy, and Cornell University
Description: This report makes the economic case for protecting and conserving nature and highlights nine policy and financing mechanisms that will secure new funding for biodiversity conservation or reduce the need for future spending through the reform of harmful subsidies.

Guide: Innovations for Coral Finance (2017) [138]
Provider: Vertigo Lab for the International Coral Reef Initiative
Description: Aimed at stakeholders involved in coral conservation, this guide introduces seven innovative financing mechanisms for the protection of coral reefs across the world. These mechanisms, both public and private-led, are complemented by a presentation of innovative business models that could be implemented to enhance coral reefs conservation finance.

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Perspective: Marine ecosystem-based management and wicked problems require incrementalism, not command and control [139]

By Jon Hare, NOAA Fisheries

Editor's note: Jon Hare is the Science and Research Director of NOAA's Northeast Fisheries Science Center in Woods Hole, Massachusetts, in the US. He oversees science related to NOAA Fisheries mission in the Northeast region (Maine to North Carolina) including marine fisheries, aquaculture, protected species, habitat, and ecosystem science. NOAA Fisheries is also actively engaged in managing multiple ocean use and deploying climate ready science and management.

In 2016 I made a career change from scientist to scientific administrator in NOAA Fisheries. Our mission [140] is to provide advice supporting fisheries, aquaculture, marine mammals, endangered species, and habitats *"backed by sound science and an ecosystem-based approach to management".* I brought a natural scientist's perspective to ecosystem-based management, emphasizing understanding the components of an ecosystem and then providing this understanding to managers as scientific advice.

The year after my career change, DeFries and Nagendra (2017) [141] described ecosystem management as a *'wicked problem* [142]*'*. What they described felt like my day-to-day: working with fishers to reduce the risk of entanglement to North Atlantic Right Whales; providing advice on how to balance the needs of offshore wind-energy development, commercial and recreational fishing, and wildlife conservation; and working to bring climate and ecosystem information into fisheries management.

By reading about and discussing the role of science in informing management, I came to realize that my perspective represented an assimilated culture, rooted in a policy making paradigm termed the "*rational comprehensive*" approach. Using this approach, institutions and trained professionals oversee and conduct comprehensive planning and decision-making to address complex problems (aka *"command-and-control"* as described by Holling and Meffe (1996) [143]).

The *"wicked-problem"* concept calls for a different approach to management and decision-making, termed incrementalism. The idea recognizes that many problems are too complex for full understanding, let alone allowing clearly defined steps and comprehensive decision-making to develop and implement one-time solutions. Incrementalism holds that each stakeholder (including scientists) has a different perspective of the issues and that decision-making represents a compromise among these different perspectives. The approach provides for continued work on a problem and implements decisions stepwise with the participation of all stakeholders.

The idea of complex socio-ecological systems is very much related to incrementalism and *"wicked problems"*. Ostrom (2009) [144] established a framework whereby knowledge is gathered on both the natural and human components of a complex system and their interactions. This knowledge is then used incrementally to manage the complex system toward desired outcomes.

These ideas resonated with me. I could see the value of incrementalism: fisheries management in the US has many elements of incrementalism largely as a result of the Regional Fishery Management Council [145] structure. Additionally, I could see that fisheries are inseparable from the larger complex socio-ecological system. I also could see the rational-comprehensive approach throughout our science and management structures and processes – working to define problems in isolation and develop one-time solutions. I realized that from my position on the frontlines of science and management, I have the opportunity to apply incrementalism and to apply the concepts of complex socio-ecological systems. As a start, I came up with 10 lessons to carry forward in my efforts to provide advice *"backed by sound science and an ecosystem-based approach to management"*.

1. Accept that fisheries are complex socio-ecological systems (explicitly acknowledging humans are part of ecosystems)
2. Strengthen existing adaptive management processes and institutions
3. Encourage and engage in participatory science (co-learning)
4. Question inertia
5. Respect all perspectives
6. Recognize fishers as knowledge experts
7. Always consider the scale of the problem
8. Be open to changing your mind and adjusting your perspective
9. Read, listen, and discuss broadly
10. Publish and communicate results of science and management

These lessons are geared toward ecosystem approaches to management in marine ecosystems. However, the "*wicked-problem*" concept, incrementalism, complex socio-ecological systems, and these 10 lessons are generally applicable to practitioners of ecosystem-based management in any system. If you are interested, these ideas are more fully explored in a Food for Thought Article published in the ICES Journal of Marine Science in 2020 [146].

Printer-friendly version [147] PDF version [148]

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