sustainability

MDPI

Article

# A Synthesis of Opportunities for Applying the Telecoupling Framework to Marine Protected Areas

**Vanessa Hull *, Christian J. Rivera and Chad Wong**

Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL 32611, USA
* Correspondence: vhull@ufl.edu

Received: 31 May 2019; Accepted: 14 August 2019; Published: 17 August 2019

**Abstract:** The world's oceans face unprecedented anthropogenic threats in the globalized era that originate from all over the world, including climate change, global trade and transportation, and pollution. Marine protected areas (MPAs) serve important roles in conservation of marine biodiversity and ecosystem resilience, but their success is increasingly challenged in the face of such large-scale threats. Here, we illustrate the utility of adopting the interdisciplinary telecoupling framework to better understand effects that originate from distant places and cross MPA boundaries (e.g., polluted water circulation, anthropogenic noise transport, human and animal migration). We review evidence of distal processes affecting MPAs and the cutting-edge approaches currently used to investigate these processes. We then introduce the umbrella framework of telecoupling and explain how it can help address knowledge gaps that exist due to limitations of past approaches that are centered within individual disciplines. We then synthesize five examples from the recent telecoupling literature to explore how the telecoupling framework can be used for MPA research. These examples include the spatial subsidies approach, adapted social network analysis, telecoupled qualitative analysis, telecoupled supply chain analysis, and decision support tools for telecoupling. Our work highlights the potential for the telecoupling framework to better understand and address the mounting and interconnected socioeconomic and environmental sustainability challenges faced by the growing number of MPAs around the world.

**Keywords:** climate change; marine protected area; spillover; telecoupling

## 1. Introduction

Marine ecosystems around the globe have profound importance for supporting both biodiversity and human societies. Covering 70% of the earth's surface, the world's oceans play key roles in climate regulation, oxygen production, transportation, recreation, and food production. However, marine environments are now facing unprecedented threats in the current human dominated era. These include sea level rise, dead zones, pollution, plastic debris, ocean acidification, fish population collapse, and invasive species. For instance, marine acidity has increased by an average of 26% since the Industrial Revolution [1]. An estimated over 5 trillion tons of plastic pieces float through the ocean globally [2] and over 500 hypoxic dead zones that support little marine life span 245,000 km$^2$, caused in part by excessive nutrient runoff [3].

One of the key strategies to combating such complex threats is establishing marine protected areas (MPAs). According to the IUCN, "A protected area is a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values" [4]. Contrary to misconceptions that may be associated with the term "protected", less than 1% of the MPA coverage is a strictly "no-take" area where human extraction (e.g., fishing, mining) is prohibited [5]. Most protected areas in marine environments are multi-use areas that are managed with a nuanced set of zones and rules about the variety of human activities and management measures that take place. In the year 2000, less than 1% of all marine waters were designated as MPAs [6]. In 2010, however, the United Nations Convention on Biological Diversity identified increasing marine protected areas as an Aichi Target goal, with the aim of conserving 10% of all marine environments in protected areas by 2020. This multinational effort has propelled protected areas forward and as of May 2019, there are 14,830 marine protected areas around the world that cover 7.59% of the total marine area [6].

MPAs have had measurable success in achieving protection goals in many places. For example, they have contributed to the survival of lobsters in Northern Europe [7], improved foraging ability of African penguins [8], prevented loss of coral cover around the globe [9], and improved livelihoods of subsistence fishermen in community-managed MPAs such as Madagascar [10]. However, MPAs have also been fraught with criticisms due to failures resulting from lack of capacity for monitoring and enforcement [11], improper location choice for maximizing biodiversity protection [12], limited connectivity and small size [13], endangerment of social equity and the rights of indigenous groups [14], and increased tension and conflict among stakeholder groups [15].

In the current modern world, one of the greatest challenges that comes with managing a finite demarcated area of protected space is that it cannot be isolated from the rest of the world. In an era with increasing global trade, human and animal migration, and invasive species spread, even seemingly remote places are impacted by a chain of events originating from somewhere else. As of 2017, the number of people undergoing international migration reached 258 million [16], international tourists exceeded 1 billion [17], and the global value of trade exports reached $17.7 trillion USD [18]. This type of frequency and magnitude of global exchange has strong implications for the marine environment, as even remote marine regions beyond national jurisdictions are influenced by distant processes via shipping of trade goods, oil and gas development, invasive species spread, climate change, and pollution [19–21]. Currently MPA management is lacking an effective framework to acknowledge and deal with these increasingly diffuse impacts.

In this paper, we explore the utility of a transdisciplinary framework called telecoupling for understanding impacts of distant places on MPAs. The telecoupling framework examines causes and effects of interactions among distant coupled human and natural systems in the globalized world (e.g., trade, migration, species invasion) [22]. Here, we (1) review the literature to synthesize past research on impacts of distant processes on MPAs, (2) introduce the telecoupling framework, and (3) provide examples to illustrate how the telecoupling framework can fill existing knowledge gaps in MPA research.

## 2. Distal Processes Affecting MPAs

Marine environments are exposed to water circulation and accompanying interactions between physical forcing and biotic processes that occur at large spatial scales exceeding those occurring in terrestrial environments [23]. MPAs in particular are inherently vulnerable to distal effects because of their locations in coastal or open ocean environments that undergo frequent long-distance flows [24]. Although MPAs have boundaries delineated on maps, in reality their boundaries are open, and they are subject to extensive outside influences, while also having substantial impacts on their surroundings (Table 1).

One of the most common types of distal effects examined in the MPA literature deals with fisheries. The term "spillover" has been used frequently in the context of MPAs in the past when referring to the positive effects of an increase in fish populations inside a protected area which in turn "spill over" to increase the biomass of fish available for fishing industries in the neighboring non-protected areas [25]. There is widespread evidence for this effect occurring with a variety of species and in MPAs in countries all over the world, particularly in the context of local artisanal fisheries [26–29]. The spatial extent and magnitude of the spillover effect may be influenced by several factors such as habitat connectivity [28] and degree of fishing pressure [30]. The positive effects of this distal process have helped to illustrate the potential value of MPAs for benefiting not only the ecosystem but also human societies and associated industries. At the same time, there are also potential negative effects of MPAs on neighboring and regional fishing communities that may experience loss of rights and access to resources, particularly for indigenous groups [31].

Another common distal effect that influences MPAs and crosses MPA boundaries is pollution. A variety of forms of pollution enter MPAs from outside sources, including light pollution, plastic pollution and other marine debris, and chemical inputs or contaminant pollution (Table 1). For example, recent global analyses show evidence of pervasive light pollution coming into MPAs from external sources [32]. Pollution is also linked to shipping lanes that may still promote plastic pollution even if the ships do not cross the MPA boundaries [33]. In addition, flows of contaminants into MPAs is evident, for example as seen in accumulation of toxins in the tissues of animals such as cetaceans that are being protected in MPAs [34].

Climate change is another distal effect that has diffuse impacts across marine environments, including MPAs. Models suggest that mean sea-surface temperatures within MPAs will warm an additional 2.8 °C by 2100 [35]. Aside from higher temperatures, other climate related changes including water acidification, sea-level rise, storm intensification, species range shifts, and decreased oxygen also affect MPAs [36]. The enormity of these challenges has spurred ongoing debates about the actual value of fixed MPAs in a world that is undergoing rapid change [35]. At the same time, recent studies also suggest that MPAs may play central roles in mitigating climate impacts at broader scales [36]. For instance, they can promote healthier food webs to allow for better carbon cycling [36].

**Table 1.** Examples showing how distal processes affect the relationship between MPAs and the broader regions in which they are found. (**a**) Impacts of outside regions on MPAs and (**b**) impacts of MPAs on outside regions.

| Process | (a) Region → MPA | (b) MPA → Region |
| --- | --- | --- |
| Pollution | • Cetaceans living in Pelagos Sanctuary in the Mediterranean have high levels of toxins in their skin due to pollution from industrial and agricultural run-off [34].<br>• Remote sensing reveals artificial light pollution is encroaching on MPAs worldwide [32].<br>• Plastic pollution is detected in six Mediterranean MPAs and is linked to shipping lanes [33]. | • Some MPAs have shown promise for mitigating pollution, such as mitigating *E. coli* levels from runoff in coral reefs off of Kenya [37]. |
| Climate change | • Global predictions suggest that mean sea-surface temperatures within MPAs will warm an additional 2.8 °C by 2100, severely affecting marine life [35].<br>• Ocean acidification is high in coastal MPAs in particular, for example the California Current large marine ecosystem (CCLME) has CO2 values up to three times the global mean [38]. | • MPAs may help offset climate change at broader scales by improving nutrient cycling and increasing resilience [36], as well as increase carbon sequestration along coasts [39].<br>• MPA networks reduce risk of population collapse in fish following climate change-induced catastrophes [40]. |
| Animal migration | • Mammal migration into MPAs sustains local tourism industries and MPA visitation [41]. | • MPAs help maintain integrity of migration pathways across a variety of marine species [42], including endangered species such as the green turtle [43]. |
| Animal (and larval) dispersal | • Protection and associated habitat improvements provided by MPAs spurs recruitment from nearby predators which can have mixed effects on food webs [44]. | • Recent research emphasizes the importance of larval dispersal for MPA effectiveness in contributing to regional marine population stability. Models that maximize MPA placement based on larval dispersal patterns show promise [45]. |
| Anthropogenic noise | • Acoustic data analysis reveals high levels of anthropogenic noise, such as in an MPA in Canada affected by regional ship travel [46]. | • "Quiet (er)" MPAs have been proposed as a means to provide safe havens for regional marine life in noisier regions to mitigate negative impacts on behavior, orientation, feeding, and mating patterns of a variety of sensitive species [47]. |
| Invasive species | • Invasive species are present in MPAs worldwide. MPAs may be more vulnerable to experiencing species invasion from outside places due to lower fishing pressure than in non-protected areas [48]. | • MPAs may help prevent regional invasive species spread in some instances and in other instances may promote invasion [48,49]. There is a paucity of available data on this issue. |
| Fisheries | • Artisanal and recreational fisheries occurring inside MPA boundaries relies on stability of outside areas. Political forces from outside of the MPA can dictate which stakeholders have access to fisheries inside [50]. | • MPAs provide protection for marine life that in turn improves regional fisheries in a variety of contexts [51].<br>• Some MPAs also cause disenchantment with neighboring fishing communities due to conflicts over access rights [31]. |

Advances in understanding distal effects on MPAs that flow in and out of MPA boundaries have been made due to the novel methods that are currently being implemented (Table 2). There are some exciting recent advances such as the "connectivity footprint" method, which identifies the connectedness of an MPA to the broader region via an ocean general circulation model and Lagrangian particle tracking [52]. This analysis in turn informs the risk of pollution from long-distance water flows.

**Table 2.** Example current methods for examining distal processes and MPAs.

| Method | Description/Examples |
|---|---|
| Ecosystem services analysis | • Comparison of ecosystem services (e.g., fisheries, tourism) provided to a coastal area inside versus outside of MPAs [53].<br>• "Extra-local" ecosystem service mapping [24] |
| Social network analysis | • Examining how social ties among actors at different local and regional levels facilitate control of lionfish invasion in MPAs [54] |
| Remote sensing change detection analysis | • Analysis of remote sensing imagery can reveal changes in ecosystem health, pollution, land cover, and population dynamics inside and outside of MPAs [55]. |
| Integrated risk assessment | • A conceptual framework for conducting risk assessment for MPAs by integrating internal and external drivers, pressures, and responses [56]. |
| Participatory approaches | • Public Participation GIS (PPGIS) to examine stakeholder values across a spatial extent that includes MPAs and other areas off of the Australia coast [57]. |
| Marine Spatial Planning (MSP) | • Use of decision-support tools to design new MPAs and MPA networks using a variety of available data on spatial distributions of resources and stakeholder needs [58]. |
| Value chain analysis | • Value chain analysis to examine fish trade (from boat to market) to determine the impact of preferences of outside tourists for various local fish species in a Brazilian MPA [59]. |
| Particle tracking models | • A hydrodynamic model used to predict sensitivity of MPAs to larval dispersal shifts in response to atmospheric cycles [60].<br>• Modeling connectivity among MPAs by tracking dispersal of kelp and sea urchins using an oceanographic forecasting model [61]. |
| Telemetry | • Acoustic telemetry data analysis can reveal changes in habitat use patterns of marine species such as sharks and turtles in and around MPAs over time [62]. |
| Bio-economic models | • Modeling of economic impacts of MPAs on income of artisanal fishers from neighboring regions [63]. |

Long-term remote sensing analyses have also been done that compare changes over time between inside MPAs and neighboring areas [55] and scenario analyses that forecast into the future [64]. Telemetry and acoustic monitoring track animal movements across MPA boundaries in ways that have not been possible in the past [62,65]. There are also novel advances available to track flows of contaminants over MPA boundaries such as via underwater sensors [66]. Social network analyses have also been applied in novel ways to examine the strength of ties among different levels of governance that come from inside and outside of an MPA [54].

While all of these advances have provided ample opportunities to better understand the connectedness of MPAs to the broader world, each method is largely discipline-specific and focused on either one process or solely on either ecological or socioeconomic phenomena. What has been largely lacking is an interdisciplinary approach that integrates simultaneous flows of both socioeconomic and ecological phenomena across MPA borders. There has recently been new interdisciplinary work in MPAs such as meta-analyses on trade-offs between human well-being and ecological systems [67] and their effectiveness [68]. However, work this far in this interdisciplinary realm is largely place-based and focused on individual MPAs and does not explicitly incorporate distal processes and multi-level effects.

## 3. The Telecoupling Framework—A Potential New Frontier for MPA Research

We argue that the umbrella conceptual framework of telecoupling may help bridge these gaps and provide a path to integrate these otherwise discipline-specific methods for examining distal effects on MPAs. Telecoupling refers to interactions between coupled human and natural systems over distances [22] (Figure 1). This transdisciplinary framework has been widely applied to better understand the scope of diverse global challenges such as those involving trade [69,70], bird and bat migration [71,72], disease spread [73], transnational land deals [74], and transnational water transfer projects [75]. In this framework, a system is composed of natural components (e.g., biophysical properties, vegetation, wildlife) and human components (e.g., societal values, sociodemographic characteristics, economic properties). A system could be a single village or an entire country, depending on the research question.

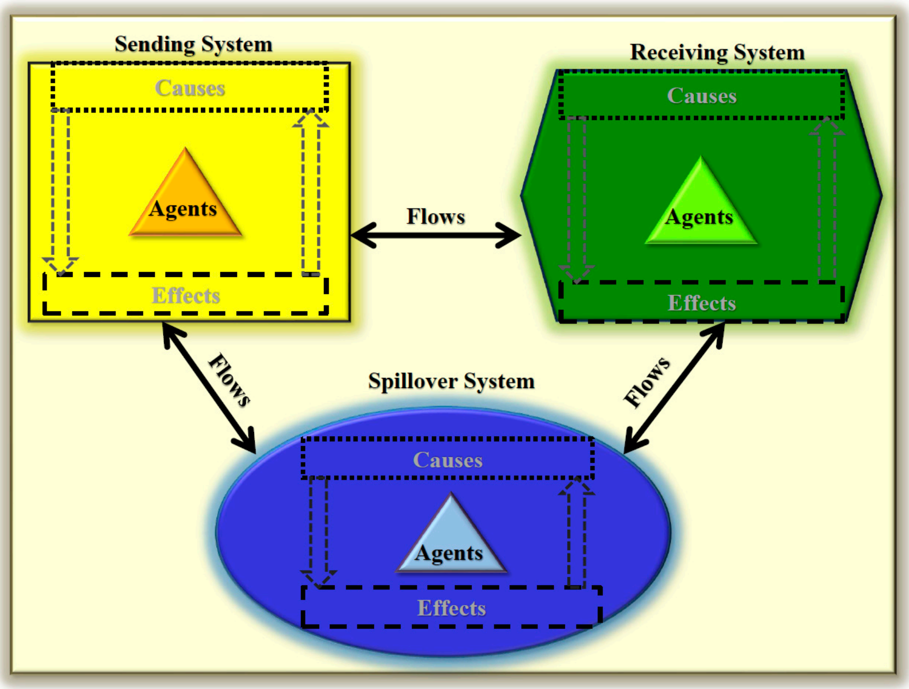


**Figure 1.** Telecoupling framework. Multiple distant coupled human and natural systems are connected by flows of matter, money, and information that travel between sending and receiving systems. Spillover systems are indirectly affected by these exchanges (e.g., as a third party in a trade agreement). Flows are facilitated by actions from agents in different systems and have diverse socio-ecological causes and effects across the distant systems. Reprinted from Liu et al. [22].

Each system is connected to one or more other systems located far away by flows of information, matter/energy, and money over distances. For instance, an agricultural trade exchange could involve transfer of food and money between two distant countries, but also could involve transfer of information about agricultural techniques or technologies. Flows also may include air or water circulation. Sending systems are those that directly transport flows to receiving systems. Agents within each system perform a variety of actions to facilitate socioeconomic and environmental causes and effects that percolate across space. Agents, for example, could be individual traders or farmers or larger entities like corporations or government agencies. Causes of a telecoupling are varied and can include economic factors (e.g., trade to promote economic growth [69]), political factors (e.g., long-distance collaboration on land deals dictated by existing political relationships [76]), or environmental factors (e.g., long-distance migration of animals to take advantage of distant food resources [71]). Effects include both socioeconomic and environmental impacts and could either positively or negatively impact sustainability of the system. These include for example improvements in economic indicators, erosion of local culture, environmental degradation, improved socio-ecological resilience, or technological innovation. Central to the framework is the idea of embracing systems thinking and interdisciplinary approaches to understanding the mechanisms and consequences of long-distance processes. The framework has also been expanded in recent years to accommodate a variety of interaction distances. The metacoupling framework differentiates between human-nature interactions within a system (intracoupling), between distant systems (telecoupling), and between adjacent systems (pericoupling) [77].

Systems that are indirectly affected by the exchange of long-distance flows are known as spillover systems [78]. Spillover systems are one of the most compelling parts of this framework, yet they are the most understudied [78,79]. Example spillover systems include a third-party country in a trade agreement influenced by changing relationships among other countries [80], a stopover location along an animal's long distance migratory pathway that receives transitory ecosystem services and disservices [81], or a place that receives air or water pollution indirectly as a result of distant trade or technology spread [82]. Spillover effects could occur adjacent to a sending/receiving system or far away, while the magnitude and direction of effects can vary [78]. Agents involved in the spillover system may be either active participants (i.e., as players in a third party in a trade agreement) or passive recipients (i.e., recipients of pollution originating from an outside source) [78]. Spillover effects can often be surprising or unpredictable, such as the recent marked decline in soybean trade from the U.S. to China as a result of the rise of availability of cheaper soybean imports into China from Brazil, an indirect effect which has profound ramifications for not only U.S. farmer livelihoods but also broad scale agroecosystem change in the U.S. [80]. Spillovers have also occurred in other neighboring ecosystems in Brazil, where the increased soybean production has promoted increased ranching of cattle and associated deforestation in neighboring biomes [70].

The way in which spillover systems are treated in the telecoupling framework differs from related concepts that have long been discussed in the literature such as "externalities" and "leakage" in that causes and effects associated with the spillover are explicitly analyzed from an interdisciplinary perspective and using a systems approach [78]. For instance, smallholder farmers around the world undergo complex decision-making processes regarding whether to embrace new farming techniques in an era of rapid agricultural change [83]. Their decisions and behaviors have spillover effects on adjacent farms around them that can be best understood by explicitly examining the interplay among social and ecological causes and effects at different spatial scales [83]. Spillover systems are important to study because they reveal hidden effects that may be under the surface and difficult to detect and in turn govern [78,79]. Methods for studying spillover systems are varied and can include network and simulation modeling, ethnographic fieldwork, and mixed-methods approaches [78]. Embracing the complexity of these systems will help guide sustainability in an increasingly interconnected world.

## 4. Opportunities for Applying the Telecoupling Framework to Marine Protected Areas

Most of the research on telecoupling to date has been conducted in terrestrial environments. Some studies have been done involving terrestrial protected areas, which have shown the extent to which even remote terrestrial reserves are connected and impacted in diverse ways by distant systems [84–87]. Effects of telecoupling on terrestrial protected areas are varied, including positive effects seen in the case of outside federal aid rescuing a protected area recovering from a natural disaster [84] and negative effects such as in the case of the rights of indigenous groups in protected areas made more vulnerable via extractive demands from transnational trade flows [85]. Some valuable telecoupling work has been done in marine environments on understanding distal causes and effects of seabird migration [71], the

Peruvian fishery industry [88], and mapping 'extra-local' ecosystem services in the marine context [24]. However, a holistic consideration of the diversity of ways in which telecoupling acts in the marine context is needed. Given the increasing distal pressures on MPAs to date, analyzing MPAs in the context of the telecoupling framework may help to illuminate the unexpected causes and consequences of distant processes for both the human and natural components of the system. Here we outline five example methods illustrating how the telecoupling framework can contribute in novel ways to MPA research (Table 3).

### 4.1. Telecoupled Ecosystem Services Approaches

There is potential for the telecoupling framework to inform understanding of ecosystem services across space as a result of distant interactions between MPAs and broader regions. Recent research has highlighted the value of MPAs for providing a variety of ecosystem services, for example in a recent assessment of services such as primary production, nutrient cycling, hazard regulation, and recreational services in several MPAs in the U.K. [89]. However, there is a need to scale up to connect MPAs to broader regions and understand the relative role of MPAs in contributing to ecosystem services via flows (e.g., larval dispersal, migration, air circulation, information flows). Potential starting points for addressing this need can be seen in terrestrial telecoupling examples. One recent study adopted a spatial subsidies approach to examining ecosystem services provided across the entire migration pathway of the Mexican free-tailed bat [81]. This study quantified the pollination and tourism services provided by bats in each state of the southwestern U.S. and Mexico as a proportion of the total services provided in the entire pathway. The study was novel in its approach to quantifying the impacts of a flow of animals and money across this transboundary environment. The approach was useful in quantifying the extent to which U.S. states were benefiting from the bats more than in Mexico, highlighting the spatial mismatch of requests from the U.S. for Mexico to fund better enforcement in protected areas for bats on the other end of the migration path even though they were receiving fewer benefits.

**Table 3.** Select example telecoupling framework research methods and how they may be useful for MPA research.

| Telecoupling Approach | Example Telecoupling Study | Potential for MPAs |
|---|---|---|
| Spatial subsidies approach | Mapping ecosystem services (tourism and pollination) across the entire migratory pathway in bats to identify relative areas of high or low benefits and associated spatial disconnects in management planning [81] | • Estimating the proportion of ecosystem service benefits of a migratory species such as green sea turtle or manatee (e.g., tourism, nutrient cycling) in an MPA and surrounding regions where they migrate.<br>• Linking multiple ecosystem services together such as integration of ecological data on flows of nutrient cycling with cultural data on information flows in and out of MPAs. |
| Adapted social network analysis | Understanding environmental and economic impacts of land competition among distant land grabbing actors in Madagascar by tracking flows among networked actors [90]. Semi-structured interviews with actors at multiple levels explicitly ask stakeholders about flow origin and direction. | • Understanding where tourism dollars go from MPAs and the extent to which different agents benefit.<br>• Mapping the pathway of fish harvests from MPAs and identifying impacts on agents at different levels.<br>• Linking different types of exchanges together across space (e.g., money, materials, ideas) and their relationship to agent networks. |
| Telecoupled qualitative analysis | Multi-site ethnographic approaches involve travel and intensive ethnographies with stakeholders at multiple sites that may be connected as sending, receiving, and spillover systems of a particular flow [91]. | • Linking causes and impacts in the fishing trade by ethnographic studies of stakeholders in both MPAs and in associated markets/consumer groups. |
| Telecoupled supply chain analysis | A suite of methods (e.g., life cycle analysis (LCA), footprints, input-output analysis) can be used for analyzing supply chains. These approaches can be telecoupled by broadening the spatial scale and explicitly incorporating spillover effects and feedback loops [92]. | • Evaluating the broader social-ecological context of trade-offs between competing industries and MPA uses, including in spillover systems. |
| Telecoupling decision support tools | The Telecoupling Toolbox GeoApp is an open-source GIS platform allowing users to specify sending, receiving and spillover systems, quantify flows between systems, and map causes and effects across space [93]. | • Working with stakeholders to visualize and map flows into/out of an MPA to better understand how it is situated in the world<br>• Engaging in scenario analysis to discern potential impacts of MPA management changes on other areas outside of the MPA |

This type of approach can be useful for understanding the ecosystem services provided by MPAs relative to their surrounding regions (including but not limited to services provided by migratory species). For example, one could track the pathway of larvae into and out of an MPA using particle tracking methods and subsequently predict relative ecosystem service benefits of the larvae at each point along the flow. Cutting edge approaches for tracking flows across space are newly becoming available and can open up new opportunities to make such determinations, including passive acoustic monitoring for marine mammals [94], hyperspectral remote sensing for detecting plastic concentrations over oceans [95], and satellite tracking of ships via technologies like SkyTruth [19]. This type of approach could identify potentially surprising spatial mismatches as was seen in the case of the Mexican free-tailed bat, such as by recognizing that an MPA that is funded to protect green sea turtles for example may be transferring services to other distant areas but not receiving compensatory support for conservation from the distant stakeholders. A spatially explicit ecosystem services analysis could also inform recent efforts to understand the value of MPAs for regional food security [96]. This information could then be paired with data on flows of cultural and recreational services across MPA borders. For example, one could track distances traveled by tourists visiting MPAs (recreational services) and whether they bring knowledge about aquatic conservation to other regions or to new agents elsewhere. One could also document the impact of flows of cultural information from neighboring fishing communities inward to an MPA to improve fisheries management. Flows could be tracked for human–nature interactions occurring not only within the MPA (intracoupling), but also with adjacent (pericoupled) and distant (telecoupled) systems. In this way a broader understanding of the global impact of the MPA could be drawn.

### *4.2. Adapted Social Network Analysis*

In addition, the telecoupling framework can be useful for augmenting traditional social network analyses. Although social network analyses have been applied to MPAs in the past [97], many studies are limited in extent to within MPA boundaries. Alexander et al. [54] recently advocated for scaling up to examine social ties via MPA "social-ecological networks" and provided a useful framework for studying the role of interactions between local and regional institutions in MPA management. This framework is focused on identifying relationships and strength of interactions via collaboration and information sharing among the different stakeholders, but it does not provide a means to track and quantify flows of information, money, and materials among the cross-scale agents. The telecoupling framework may provide a starting point to fill this gap by explicitly linking flows and causes and impacts. For example, a recent telecoupling study conducted on land grabbing in Madagascar adopted an adapted social network approach in which researchers explicitly asked interviewees in a local village about flows of materials with questions such as "Who did you exchange (goods, financial capital, human resources) with?" [90]. Follow-up questions addressed deeper causes and impacts of these interactions. Interviewers then conducted snowball sampling to interview identified stakeholder groups at local, district, and national levels to better understand the cause and effect of the flows at the other (receiving and spillover) ends. Researchers then mapped the flows among agents from different levels using network graphs and were thus better able to understand the complex and multi-scaled process of land grabbing in this region. This approach can also be extended to embrace the metacoupling framework by differentiating social and institutional interactions that take place at different distances from within systems (intracoupling), among adjacent systems (pericoupling), and among more distant systems (telecoupling) [77].

This type of approach could be useful for MPA management by providing a means to track distant flows of for example tourism dollars, fish harvests, or management techniques. How far do fish harvests from MPAs travel and how do exchanges enhance or hinder relationships among agents at different levels? How does this in turn feed back to impact MPA management? Do MPAs facilitate stronger or weaker local-regional social linkages among user groups and what does this mean for sustainability? Much of the past terrestrial telecoupling research has suggested that strong ties in multi-level management and governance have positive effects on sustainability by promoting better information flow among users and decision makers. This has been demonstrated with smallholder farmers [83] and global food trade [98]. However, whether the same is true for MPAs needs to be determined. There is a particular need for a better understanding of social networks involved in governance of remote Areas Beyond Jurisdiction (ABJ) areas. Marine exploitation was historically limited by access to remote locations, but has significantly opened up in recent years due to technology innovations. Telecoupled social network analysis in these areas that are on the receiving end of flows from many interacting distant actors would help to better inform management of emerging international conflicts.

### 4.3. Telecoupled Qualitative Analysis

One of the challenges encountered in telecoupling research to date is that the data may not yet exist in some instances to examine long-distance interactions among coupled systems. In these cases, qualitative analysis is particularly meaningful to reveal new phenomena that have not yet been documented and obtain a depth of information that may only be gleaned by extensive informal interactions with people. Nielsen et al. [91] provide examples of qualitative analysis techniques for telecoupling, including multi-site ethnography. The authors have had success in using ethnography to understand land grabbing for banana trade in Laos, a newer phenomenon that is rapidly transforming the landscape. Ethnographic approaches proved valuable for identifying the importance of the nuances in informal relationships among distant Laos farmers and Chinese corporations that played a significant role in shaping land use changes.

Some powerful ethnographic studies have been conducted in MPAs in the past. For example, in studies on social complexity and interactions between illegal fishing and conservation in the Philippines [99], gendered differences in fisheries access in an MPA in Madagascar [100], and politics and disempowerment in indigenous communities in and around an MPA in Tanzania [31]. However, a multi-site ethnography examining a distant process that links two or more distant sites has to our knowledge not yet been conducted for MPAs. This approach could be meaningful for example in examining processes impacting remote protected areas that are becoming increasingly connected to the rest of the world via fisheries. One case is the Wakatobi Marine Park in Indonesia, where the indigenous Sama-Bajo people reside. This unique group, which relies heavily on fishing for their livelihood and cultural identity, has been extensively studied via ethnography [101]. However, practices and stakeholder groups have evolved, as there is increasing pressure from outside fisheries to supply fish and sea urchin markets throughout Asia. There is currently no coupled understanding that links harvesting and associated ecological threats in this MPA to social processes occurring in outside fish markets or to consumer behavior in the broader region. This disconnect prevents measures from being made to control outside pressures and in turn potentially protect both indigenous rights and the sustainability of species such as the sea urchin in this region. A multi-site ethnography that follows the telecoupled flow from sending to receiving ends could begin to close this gap.

### 4.4. Telecoupled Supply Chain Analysis

Parra Paitan and Verburg [92] recently highlighted the various applications of supply chain analyses for telecoupling research on agriculture. They discuss the potential for common approaches such as life cycle analysis, input–output methods, footprint analysis and agent-based models to be enhanced via adopting a telecoupled lens. The main idea of these approaches is to quantify diverse social and environmental impacts along the pathway of a given product. The authors conclude that adapting the approaches to fit a telecoupled lens may perhaps be best achieved by implementing hybrid methods that bring together multiple approaches to overcome the inherent limitations of each single approach. For example, Millington et al. [102] paired an agent-based model on farmer land use decision-making with general equilibrium models on agricultural markets and systems dynamics models on flows. The approach was demonstrated using an example examining soybean trade between

Brazil and China (with the U.S. as a spillover country) and allowed for testing scenarios of changes in pricing, land use, and agent behavior to observe a variety of impacts on the distant systems.

For agriculture, it would be a 'farm to table' pathway, but in the case of marine environments, there could be a parallel 'boat to table' approach for fisheries or origin-to-destination pathway for tourism. Such approaches have already been used in MPA literature for a variety of purposes, such as predicting impacts of new MPAs on fisheries and shipping in the Gulf of Maine using input-output models [103] and life cycle analysis of toothfish fisheries in and around an MPA in Australia [104]. However, thus far there have not been efforts to conduct hybrid approaches that would enable combining pricing models with agent behavior models and land use change models together to connect different changes occurring across the distant affected systems. This type of approach could enhance a major recent thrust in the MPA literature to better understand trade-offs in MPAs. This includes trade-offs between engaging in different industries (e.g., fishing vs. tourism) [53,105] and trade-offs between ecological resources (supply) and the well-being of users (demand) [67,106] in MPAs. Insights about such trade-offs are important because they shape decision-making on MPA management, but thus far have not been able to capture driving forces from distant places that may affect these competing forces.

### *4.5. Telecoupling Framework and Decision Support Tools*

The telecoupling framework also has the capability of contributing to analyses of Big Data. Online data sharing platforms such as NOAA's climatic data center (https://www.ncdc.noaa.gov/) provide exciting new frontiers for research on MPAs. Decision support platforms are also available for a variety of purposes, including for facilitating marine spatial planning [107]. However, such platforms could be more integrative of different types of data and also do not provide a user-friendly means to examine long-distance flows of materials and the associated causes and impacts of those flows. The Telecoupling Toolbox GeoApp, an open-source GIS mapping tool, may help fill this gap [93]. The user can specify locations of sending, receiving, and spillover systems and then visualize the spatial flows that occur among these systems. Widgets are also becoming available to conduct analyses on effects of the flows such as calculations of $CO_2$ emissions from distant travels, and blue carbon storage in coastal areas over time. The toolbox has been used, for example, to map international tourism flows to a remote nature reserve in China for giant panda conservation [93].

This type of approach could be useful for MPA research for example with engaging in mapping and visualization techniques with MPA stakeholders to understand the flows going in and out of the MPA and associated causes and effects of those flows. This would allow MPA managers to have a broader perspective of how the MPA is situated on the globe and identify any new agents at regional levels who may be impacted by MPA activities and with whom they may want to engage with further in the future. This is particularly the case for spillover systems that may not be previously acknowledged, such as other coastal areas indirectly affected by nutrient transport or larval dispersal, other markets or countries that are third parties in fishing trade exchanges, and other MPAs that may be connected by previously underappreciated networks of information, pollution, or migration flows. Users could also conduct scenario analysis via a more quantitative approach to try to predict for example what surprises could emerge in a distant market or coastal area when an MPA changes a policy on allowable take or closes a region to fishing (or to tourism).

## 5. Conclusions

The MPA research and management community has recently begun to explore measures to address increasing globalized threats. This can be seen in the trend of proposing increasingly large marine protected areas [108,109], managing for connected networks of protected areas [110], and calls for ecosystem management [111] and regional planning and management [13]. These trends exemplify a shift toward scaling up MPA management [19]. We have argued here that the telecoupling framework can inform this shift in thinking. The current globalized era presents unique challenges for MPA research, management, and governance in the face of distant impacts. Challenges include limited financial resources, lack of capacity, inadequate political will, and conflicts across different cultures and value systems [19]. However, there are also unprecedented opportunities to work together to identify socioeconomic and environmental synergies that can be revealed by using an integrated systems approach. In the face of ocean acidification, depleted global fish stocks, rising sea levels, and mounting pollution, such efforts are needed in order to ensure that MPAs are in the best position to contribute to ocean sustainability for future generations.

**Author Contributions:** Conceptualization—V.H., C.J.R., C.W.; Writing—Original draft V.H., C.J.R., C.W.; Writing—Review and editing V.H., C.J.R., C.W.

**Funding:** This research received no external funding.

**Acknowledgments:** We thank anonymous peer reviewers for their helpful feedback to improve this work.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. United Nations. UN Sustainable Development Goals. Available online: https://sustainabledevelopment.un.org/sdgs (accessed on 15 May 2019).
2. Eriksen, M.; Lebreton, L.C.; Carson, H.S.; Thiel, M.; Moore, C.J.; Borerro, J.C.; Galgani, F.; Ryan, P.G.; Reisser, J. Plastic pollution in the world's oceans: More than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PLoS ONE* **2014**, *9*, e111913. [CrossRef] [PubMed]
3. Diaz, R.J.; Rosenberg, R. Spreading dead zones and consequences for marine ecosystems. *Science* **2008**, *321*, 926–929. [CrossRef] [PubMed]
4. IUCN. Protected Areas. Available online: https://www.iucn.org/theme/protected-areas/about (accessed on 15 May 2019).
5. Costello, M.J.; Ballantine, B. Biodiversity conservation should focus on no-take Marine Reserves: 94% of Marine Protected Areas allow fishing. *Trends Ecol. Evol.* **2015**, *30*, 507–509. [CrossRef] [PubMed]
6. United Nations. Protected Planet. Available online: https://www.protectedplanet.net/marine (accessed on 15 May 2019).
7. Huserbraten, M.B.O.; Moland, E.; Knutsen, H.; Olsen, E.M.; André, C.; Stenseth, N.C. Conservation, spillover and gene flow within a network of Northern European marine protected areas. *PLoS ONE* **2013**, *8*, e73388. [CrossRef] [PubMed]
8. Pichegru, L.; Grémillet, D.; Crawford, R.; Ryan, P. Marine no-take zone rapidly benefits endangered penguin. *Biol. Lett.* **2010**, *6*, 498–501. [CrossRef] [PubMed]
9. Selig, E.R.; Bruno, J.F. A global analysis of the effectiveness of marine protected areas in preventing coral loss. *PLoS ONE* **2010**, *5*, e9278. [CrossRef] [PubMed]
10. United Nations Development Programme. *Village of Andavadoaka, Madagascar*; Equator Initiative Case Study Series; UNDP: New York, NY, USA, 2012; Available online: https://californiampas.org/wp-content/uploads/2016/08/Madagascar_Andavadoaka_Village_MPA_Case_Study.pdf (accessed on 15 May 2019).
11. Gill, D.A.; Mascia, M.B.; Ahmadia, G.N.; Glew, L.; Lester, S.E.; Barnes, M.; Craigie, I.; Darling, E.S.; Free, C.M.; Geldmann, J. Capacity shortfalls hinder the performance of marine protected areas globally. *Nature* **2017**, *543*, 665. [CrossRef] [PubMed]
12. Klein, C.J.; Brown, C.J.; Halpern, B.S.; Segan, D.B.; McGowan, J.; Beger, M.; Watson, J.E. Shortfalls in the global protected area network at representing marine biodiversity. *Sci. Rep.* **2015**, *5*, 17539. [CrossRef] [PubMed]
13. Agardy, T.; Di Sciara, G.N.; Christie, P. Mind the gap: Addressing the shortcomings of marine protected areas through large scale marine spatial planning. *Mar. Policy* **2011**, *35*, 226–232. [CrossRef]
14. Gray, N.J. Sea change: Exploring the international effort to promote marine protected areas. *Conserv. Soc.* **2010**, *8*, 331. [CrossRef]
15. Christie, P. Marine protected areas as biological successes and social failures in Southeast Asia. *Am. Fish. Soc. Symp.* **2004**, *42*, 155–164.

16. United Nations. *International Migration Report 2017: Highlights (ST/ESA/SER.A/404)*; Department of Economic and Social Affairs, Population Division: New York, NY, USA, 2017. Available online: https://www.un.org/en/development/desa/population/migration/publications/migrationreport/docs/MigrationReport2017_Highlights.pdf (accessed on 15 May 2019).
17. The World Bank. International Tourism, Number of Arrivals. Available online: https://data.worldbank.org/indicator/st.int.arvl (accessed on 15 May 2019).
18. United Nations. UNCTADStat. Available online: https://unctadstat.unctad.org/wds/TableViewer/tableView.aspx?ReportId=101 (accessed on 15 May 2019).
19. Ban, N.C.; Whitney, C.; Davies, T.E.; Buscher, E.; Lancaster, D.; Eckert, L.; Rhodes, C.; Jacob, A.L. Conservation Actions at Global and Local Scales in Marine Social–Ecological Systems: Status, Gaps, and Ways Forward. In *Conservation for the Anthropocene Ocean*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 143–168.
20. Österblom, H.; Crona, B.I.; Folke, C.; Nyström, M.; Troell, M. Marine ecosystem science on an intertwined planet. *Ecosystems* **2017**, *20*, 54–61. [CrossRef]
21. Tickler, D.; Meeuwig, J.J.; Palomares, M.-L.; Pauly, D.; Zeller, D. Far from home: Distance patterns of global fishing fleets. *Sci. Adv.* **2018**, *4*, eaar3279. [CrossRef] [PubMed]
22. Liu, J.; Hull, V.; Batistella, M.; DeFries, R.; Dietz, T.; Fu, F.; Hertel, T.; Izaurralde, R.C.; Lambin, E.; Li, S.; et al. Framing sustainability in a telecoupled world. *Ecol. Soc.* **2013**, *18*, 18. [CrossRef]
23. Hyrenbach, K.D.; Forney, K.A.; Dayton, P.K. Marine protected areas and ocean basin management. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2000**, *10*, 437–458. [CrossRef]
24. Drakou, E.G.; Pendleton, L.; Effron, M.; Ingram, J.C.; Teneva, L. When ecosystems and their services are not co-located: Oceans and coasts. *ICES J. Mar. Sci.* **2017**, *74*, 1531–1539. [CrossRef]
25. McClanahan, T.R.; Mangi, S. Spillover of exploitable fishes from a marine park and its effect on the adjacent fishery. *Ecol. Appl.* **2000**, *10*, 1792–1805. [CrossRef]
26. Stobart, B.; Warwick, R.; González, C.; Mallol, S.; Díaz, D.; Reñones, O.; Goñi, R. Long-term and spillover effects of a marine protected area on an exploited fish community. *Mar. Ecol. Prog. Ser.* **2009**, *384*, 47–60. [CrossRef]
27. Goñi, R.; Adlerstein, S.; Alvarez-Berastegui, D.; Forcada, A.; Reñones, O.; Criquet, G.; Polti, S.; Cadiou, G.; Valle, C.; Lenfant, P.; et al. Spillover from six western Mediterranean marine protected areas: Evidence from artisanal fisheries. *Mar. Ecol. Prog. Ser.* **2008**, *366*, 159–174. [CrossRef]
28. Forcada, A.; Valle, C.; Bonhomme, P.; Criquet, G.; Cadiou, G.; Lenfant, P.; Sánchez-Lizaso, J.L. Effects of habitat on spillover from marine protected areas to artisanal fisheries. *Mar. Ecol. Prog. Ser.* **2009**, *379*, 197–211. [CrossRef]
29. Abesamis, R.A.; Russ, G.R. Density-dependent spillover from a marine reserve: Long-term evidence. *Ecol. Appl.* **2005**, *15*, 1798–1812. [CrossRef]
30. Goñi, R.; Hilborn, R.; Díaz, D.; Mallol, S.; Adlerstein, S. Net contribution of spillover from a marine reserve to fishery catches. *Mar. Ecol. Prog. Ser.* **2010**, *400*, 233–243. [CrossRef]
31. Kamat, V.R. Dispossession and disenchantment: The micropolitics of marine conservation in southeastern Tanzania. *Mar. Policy* **2018**, *88*, 261–268. [CrossRef]
32. Davies, T.W.; Duffy, J.P.; Bennie, J.; Gaston, K.J. Stemming the tide of light pollution encroaching into marine protected areas. *Conserv. Lett.* **2016**, *9*, 164–171. [CrossRef]
33. Liubartseva, S.; Coppini, G.; Lecci, R. Are Mediterranean Marine Protected Areas sheltered from plastic pollution? *Mar. Pollut. Bull.* **2019**, *140*, 579–587. [CrossRef]
34. Fossi, M.C.; Panti, C.; Marsili, L.; Maltese, S.; Spinsanti, G.; Casini, S.; Caliani, I.; Gaspari, S.; Muñoz-Arnanz, J.; Jimenez, B.; et al. The Pelagos Sanctuary for Mediterranean marine mammals: Marine Protected Area (MPA) or marine polluted area? The case study of the striped dolphin (Stenella coeruleoalba). *Mar. Pollut. Bull.* **2013**, *70*, 64–72. [CrossRef]
35. Bruno, J.F.; Bates, A.E.; Cacciapaglia, C.; Pike, E.P.; Amstrup, S.C.; van Hooidonk, R.; Henson, S.A.; Aronson, R.B. Climate change threatens the world's marine protected areas. *Nat. Clim. Chang.* **2018**, *8*, 499. [CrossRef]
36. Roberts, C.M.; O'Leary, B.C.; McCauley, D.J.; Cury, P.M.; Duarte, C.M.; Lubchenco, J.; Pauly, D.; Sáenz-Arroyo, A.; Sumaila, U.R.; Wilson, R.W.; et al. Marine reserves can mitigate and promote adaptation to climate change. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 6167–6175. [CrossRef]

37. Njogu, A.K.; Villiers, S.D.; Wambua, S.M. Does protection of marine areas safeguard coral reefs from human-source pollution? *Front. Environ. Sci.* **2019**, *7*, 89.
38. Klinger, T.; Chornesky, E.A.; Whiteman, E.A.; Chan, F.; Largier, J.L.; Wakefield, W.W. Using integrated, ecosystem-level management to address intensifying ocean acidification and hypoxia in the California Current large marine ecosystem. *Elem. Sci. Anth.* **2017**, *5*. [CrossRef]
39. Howard, J.; McLeod, E.; Thomas, S.; Eastwood, E.; Fox, M.; Wenzel, L.; Pidgeon, E. The potential to integrate blue carbon into MPA design and management. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2017**, *27*, 100–115. [CrossRef]
40. Aalto, E.A.; Micheli, F.; Boch, C.A.; Espinoza Montes, J.A.; Woodson, C.B.; De Leo, G.A. Catastrophic Mortality, Allee Effects, and Marine Protected Areas. *Am. Nat.* **2019**, *193*, 391–408. [CrossRef]
41. Higham, J.E.; Lück, M. *Marine Wildlife and Tourism Management: Insights from the Natural and Social Sciences*; CABI: Wallingford, UK, 2007.
42. Reynolds, S.D.; Norman, B.M.; Beger, M.; Franklin, C.E.; Dwyer, R.G. Movement, distribution and marine reserve use by an endangered migratory giant. *Divers. Distrib.* **2017**, *23*, 1268–1279. [CrossRef]
43. Hays, G.C.; Mortimer, J.A.; Ierodiaconou, D.; Esteban, N. Use of long-distance migration patterns of an endangered species to inform conservation planning for the world's largest marine protected area. *Conserv. Biol.* **2014**, *28*, 1636–1644. [CrossRef]
44. Clements, C.S.; Hay, M.E. Size matters: Predator outbreaks threaten foundation species in small Marine Protected Areas. *PLoS ONE* **2017**, *12*, e0171569. [CrossRef]
45. Krueck, N.C.; Ahmadia, G.N.; Green, A.; Jones, G.P.; Possingham, H.P.; Riginos, C.; Treml, E.A.; Mumby, P.J. Incorporating larval dispersal into MPA design for both conservation and fisheries. *Ecol. Appl.* **2017**, *27*, 925–941. [CrossRef]
46. Allen, A.S.; Yurk, H.; Vagle, S.; Pilkington, J.; Canessa, R. The underwater acoustic environment at SGaan Kinghlas-Bowie Seamount Marine Protected Area: Characterizing vessel traffic and associated noise using satellite AIS and acoustic datasets. *Mar. Pollut. Bull.* **2018**, *128*, 82–88. [CrossRef]
47. Williams, R.; Erbe, C.; Ashe, E.; Clark, C.W. Quiet (er) marine protected areas. *Mar. Pollut. Bull.* **2015**, *100*, 154–161. [CrossRef]
48. Giakoumi, S.; Pey, A. Assessing the effects of marine protected areas on biological invasions: A global review. *Front. Environ. Sci.* **2017**, *4*, 49. [CrossRef]
49. Caselle, J.E.; Davis, K.; Marks, L.M. Marine management affects the invasion success of a non-native species in a temperate reef system in California, USA. *Ecol. Lett.* **2018**, *21*, 43–53. [CrossRef]
50. Hogg, K.; Noguera-Méndez, P.; Semitiel-García, M.; Gray, T.; Young, S. Controversies over stakeholder participation in marine protected area (MPA) management: A case study of the Cabo de Palos-Islas Hormigas MPA. *Ocean Coast. Manag.* **2017**, *144*, 120–128. [CrossRef]
51. Bucaram, S.J.; Hearn, A.; Trujillo, A.M.; Rentería, W.; Bustamante, R.H.; Morán, G.; Reck, G.; García, J.L. Assessing fishing effects inside and outside an MPA: The impact of the Galapagos Marine Reserve on the Industrial pelagic tuna fisheries during the first decade of operation. *Mar. Policy* **2018**, *87*, 212–225. [CrossRef]
52. Robinson, J.; New, A.; Popova, E.; Srokosz, M.; Yool, A. Far-field connectivity of the UK's four largest marine protected areas: Four of a kind? *Earth's Future* **2017**, *5*, 475–494. [CrossRef]
53. Lopes, P.F.M.; Pacheco, S.; Clauzet, M.; Silvano, R.A.M.; Begossi, A. Fisheries, tourism, and marine protected areas: Conflicting or synergistic interactions? *Ecosyst. Serv.* **2015**, *16*, 333–340. [CrossRef]
54. Alexander, S.M.; Armitage, D.; Carrington, P.J.; Bodin, Ö. Examining horizontal and vertical social ties to achieve social–ecological fit in an emerging marine reserve network. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2017**, *27*, 1209–1223. [CrossRef]
55. Ouellette, W.; Getinet, W. Remote sensing for marine spatial planning and integrated coastal areas management: Achievements, challenges, opportunities and future prospects. *Remote Sens. Appl. Soc. Environ.* **2016**, *4*, 138–157. [CrossRef]
56. Xu, E.G.B.; Leung, K.M.Y.; Morton, B.; Lee, J.H.W. An integrated environmental risk assessment and management framework for enhancing the sustainability of marine protected areas: The Cape d'Aguilar Marine Reserve case study in Hong Kong. *Sci. Total Environ.* **2015**, *505*, 269–281. [CrossRef]
57. Strickland-Munro, J.; Kobryn, H.; Brown, G.; Moore, S.A. Marine spatial planning for the future: Using Public Participation GIS (PPGIS) to inform the human dimension for large marine parks. *Mar. Policy* **2016**, *73*, 15–26. [CrossRef]

58. Lombard, A.T.; Ban, N.C.; Smith, J.L.; Lester, S.E.; Sink, K.J.; Wood, S.A.; Jacob, A.L.; Kyriazi, Z.; Tingey, R.; Sims, H.E. Practical Approaches and Advances in Spatial Tools to Achieve Multi-Objective Marine Spatial Planning. *Front. Environ. Sci.* **2019**, *6*. [CrossRef]
59. Lopes, P.F.M.; Mendes, L.; Fonseca, V.; Villasante, S. Tourism as a driver of conflicts and changes in fisheries value chains in Marine Protected Areas. *J. Environ. Manag.* **2017**, *200*, 123–134. [CrossRef]
60. Fox, A.D.; Henry, L.-A.; Corne, D.W.; Roberts, J.M. Sensitivity of marine protected area network connectivity to atmospheric variability. *R. Soc. Open Sci.* **2016**, *3*, 160494. [CrossRef]
61. Coleman, M.A.; Cetina-Heredia, P.; Roughan, M.; Feng, M.; van Sebille, E.; Kelaher, B.P. Anticipating changes to future connectivity within a network of marine protected areas. *Glob. Chang. Biol.* **2017**, *23*, 3533–3542. [CrossRef]
62. Lea, J.S.; Humphries, N.E.; von Brandis, R.G.; Clarke, C.R.; Sims, D.W. Acoustic telemetry and network analysis reveal the space use of multiple reef predators and enhance marine protected area design. *Proc. R. Soc. B Biol. Sci.* **2016**, *283*, 20160717. [CrossRef]
63. Madrigal-Ballestero, R.; Albers, H.J.; Capitán, T.; Salas, A. Marine protected areas in Costa Rica: How do artisanal fishers respond? *Ambio* **2017**, *46*, 787–796. [CrossRef]
64. Davies, T.E.; Maxwell, S.M.; Kaschner, K.; Garilao, C.; Ban, N.C. Large marine protected areas represent biodiversity now and under climate change. *Sci. Rep.* **2017**, *7*, 9569. [CrossRef]
65. Merchant, N.D.; Pirotta, E.; Barton, T.R.; Thompson, P.M. Soundscape and noise exposure monitoring in a marine protected area using shipping data and time-lapse footage. In *The Effects of Noise on Aquatic Life*, 2nd ed.; Springer: Berlin/Heidelberg, Germany, 2016; pp. 705–712.
66. Tonacci, A.; Lacava, G.; Lippa, M.A.; Lupi, L.; Cocco, M.; Domenici, C. Electronic nose and AUV: A novel perspective in marine pollution monitoring. *Mar. Technol. Soc. J.* **2015**, *49*, 18–24. [CrossRef]
67. Davies, T.E.; Epstein, G.; Aguilera, S.E.; Brooks, C.M.; Cox, M.; Evans, L.S.; Maxwell, S.M.; Nenadovic, M.; Ban, N.C. Assessing trade-offs in large marine protected areas. *PLoS ONE* **2018**, *13*, e0195760. [CrossRef]
68. Ban, N.C.; Davies, T.E.; Aguilera, S.E.; Brooks, C.; Cox, M.; Epstein, G.; Evans, L.S.; Maxwell, S.M.; Nenadovic, M. Social and ecological effectiveness of large marine protected areas. *Glob. Chang. Biol.* **2017**, *43*, 82–91. [CrossRef]
69. Xiong, H.; Millington, J.D.; Xu, W. Trade in the telecoupling framework: Evidence from the metals industry. *Ecol. Soc.* **2018**, *23*, 11. [CrossRef]
70. Dou, Y.; Liu, J. Modeling telecoupled systems: Design for simulating telecoupled soybean trade. In Proceedings of the 20th Annual Conference on Global Economic Analysis, West Lafayette, IN, USA, 7–9 June 2017; pp. 7–9.
71. Raya Rey, A.; Pizarro, J.; Anderson, C.; Huettmann, F. Even at the uttermost ends of the Earth: How seabirds telecouple the Beagle Channel with regional and global processes that affect environmental conservation and social-ecological sustainability. *Ecol. Soc.* **2017**, *22*, 31. [CrossRef]
72. López-Hoffman, L.; Diffendorfer, J.; Wiederholt, R.; Thogmartin, W.; McCracken, G.; Medellin, R.; Semmens, D. Operationalizing the telecoupling framework by calculating spatial subsidies in the ecosystem services of migratory Mexican free-tailed bats. *Ecol. Soc.* **2017**, *22*, 23. [CrossRef]
73. Easter, T.; Killion, A.; Carter, N. Climate change, cattle, and the challenge of sustainability in a telecoupled system in Africa. *Ecol. Soc.* **2018**, *23*, 10. [CrossRef]
74. Baird, I.; Fox, J. How land concessions affect places elsewhere: Telecoupling, political ecology, and large-scale plantations in southern Laos and northeastern Cambodia. *Land* **2015**, *4*, 436–453. [CrossRef]
75. Deines, J.M.; Liu, X.; Liu, J. Telecoupling in urban water systems: An examination of Beijing's imported water supply. *Water Int.* **2016**, *41*, 251–270. [CrossRef]
76. Friis, C.; Nielsen, J. Land-use change in a telecoupled world: The relevance and applicability of the telecoupling framework in the case of banana plantation expansion in Laos. *Ecol. Soc.* **2017**, *22*, 1–17. [CrossRef]
77. Liu, J. Integration across a metacoupled planet. *Ecol. Soc.* **2017**, *22*, 29. [CrossRef]
78. Liu, J.; Dou, Y.; Batistella, M.; Challies, E.; Connor, T.; Friis, C.; Millington, J.D.; Parish, E.; Romulo, C.L.; Silva, R.F.B.; et al. Spillover systems in a telecoupled Anthropocene: Typology, methods, and governance for global sustainability. *Curr. Opin. Environ. Sustain.* **2018**, *33*, 58–69. [CrossRef]
79. Hull, V.; Liu, J. Telecoupling: A new frontier for global sustainability. *Ecol. Soc.* **2018**, *23*, 41. [CrossRef]
80. Sun, J.; Tong, Y.-X.; Liu, J. Telecoupled land-use changes in distant countries. *J. Integr. Agric.* **2017**, *16*, 368–376. [CrossRef]

81. López-Hoffman, L.; Diffendorfer, J.; Wiederholt, R.; Bagstad, K.; Thogmartin, W.; McCracken, G.; Medellin, R.; Russell, A.; Semmens, D. Operationalizing the telecoupling framework for migratory species using the spatial subsidies approach to examine ecosystem services provided by Mexican free-tailed bats. *Ecol. Soc.* **2017**, *22*, 23. [CrossRef]
82. Rulli, M.C.; Casirati, S.; Dell'Angelo, J.; Davis, K.F.; Passera, C.; D'Odorico, P. Interdependencies and telecoupling of oil palm expansion at the expense of Indonesian rainforest. *Renew. Sustain. Energy Rev.* **2019**, *105*, 499–512. [CrossRef]
83. Zimmerer, K.S.; Lambin, E.; Vanek, S.J. Smallholder telecoupling and potential sustainability. *Ecol. Soc.* **2018**, *23*, 17. [CrossRef]
84. Zhang, J.; Connor, T.; Yang, H.; Ouyang, Z.; Li, S.; Liu, J. Complex effects of natural disasters on protected areas through altering telecouplings. *Ecol. Soc.* **2018**, *23*, 17. [CrossRef]
85. Boillat, S.; Gerber, J.-D.; Oberlack, C.; Zaehringer, J.; Ifejika Speranza, C.; Rist, S. Distant interactions, power, and environmental justice in protected area governance: A telecoupling perspective. *Sustainability* **2018**, *10*, 3954. [CrossRef]
86. Yang, H.; Lupi, F.; Zhang, J.; Chen, X.; Liu, J. Feedback of telecoupling: The case of a payments for ecosystem services program. *Ecol. Soc.* **2018**, *23*, 45. [CrossRef]
87. Liu, J.; Hull, V.; Luo, J.; Yang, W.; Liu, W.; Viña, A.; Vogt, C.; Xu, Z.; Yang, H.; Zhang, J.; et al. Multiple telecouplings and their complex interrelationships. *Ecol. Soc.* **2015**, *20*, 44. [CrossRef]
88. Carlson, A.; Taylor, W.; Liu, J.; Orlic, I. Peruvian anchoveta as a telecoupled fisheries system. *Ecol. Soc.* **2018**, *23*, 35. [CrossRef]
89. Potts, T.; Burdon, D.; Jackson, E.; Atkins, J.; Saunders, J.; Hastings, E.; Langmead, O. Do marine protected areas deliver flows of ecosystem services to support human welfare? *Mar. Policy* **2014**, *44*, 139–148. [CrossRef]
90. Andriamihaja, O.R.; Metz, F.; Zaehringer, J.G.; Fischer, M.; Messerli, P. Land competition under telecoupling: Distant actors' environmental versus economic claims on land in North-Eastern Madagascar. *Sustainability* **2019**, *11*, 851. [CrossRef]
91. Nielsen, J.Ø.; Hauer, J.; Friis, C. Toolbox: Capturing and Understanding Telecoupling through Qualitative Research. In *Telecoupling*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 303–312.
92. Parra Paitan, C.; Verburg, P.H. Methods to Assess the Impacts and Indirect Land Use Change Caused by Telecoupled Agricultural Supply Chains: A Review. *Sustainability* **2019**, *11*, 1162. [CrossRef]
93. Tonini, F.; Liu, J. Telecoupling toolbox: Spatially explicit tools for studying telecoupled human and natural systems. *Ecol. Soc.* **2017**, *22*, 11. [CrossRef]
94. Sousa-Lima, R.S.; Norris, T.F.; Oswald, J.N.; Fernandes, D.P. A Review and Inventory of Fixed Autonomous Recorders for Passive Acoustic Monitoring of Marine Mammals. *Aquat. Mamm.* **2013**, *39*, 205–210. [CrossRef]
95. Goddijn-Murphy, L.; Peters, S.; Van Sebille, E.; James, N.A.; Gibb, S. Concept for a hyperspectral remote sensing algorithm for floating marine macro plastics. *Mar. Pollut. Bull.* **2018**, *126*, 255–262. [CrossRef]
96. Cabral, R.B.; Halpern, B.S.; Lester, S.E.; White, C.; Gaines, S.D.; Costello, C. Designing MPAs for food security in open-access fisheries. *Sci. Rep.* **2019**, *9*, 8033. [CrossRef]
97. Markantonatou, V.; Noguera-Méndez, P.; Semitiel-García, M.; Hogg, K.; Sano, M. Social networks and information flow: Building the ground for collaborative marine conservation planning in Portofino Marine Protected Area (MPA). *Ocean Coast. Manag.* **2016**, *120*, 29–38. [CrossRef]
98. Oberlack, C.; Boillat, S.; Brönnimann, S.; Gerber, J.-D.; Heinimann, A.; Ifejika Speranza, C.; Messerli, P.; Rist, S.; Wiesmann, U. Polycentric governance in telecoupled resource systems. *Ecol. Soc.* **2018**, *23*, 16. [CrossRef]
99. Fabinyi, M.; Knudsen, M.; Segi, S. Social complexity, ethnography and coastal resource management in the Philippines. *Coast. Manag.* **2010**, *38*, 617–632. [CrossRef]
100. Baker-Médard, M. Gendering marine conservation: The politics of marine protected areas and fisheries access. *Soc. Nat. Resour.* **2017**, *30*, 723–737. [CrossRef]
101. Elliott, G.; Mitchell, B.; Wiltshire, B.; Manan, I.A.; Wismer, S. Community participation in marine protected area management: Wakatobi National Park, Sulawesi, Indonesia. *Coast. Manag.* **2001**, *29*, 295–316.
102. Millington, J.; Xiong, H.; Peterson, S.; Woods, J. Integrating modelling approaches for understanding telecoupling: Global food trade and local land use. *Land* **2017**, *6*, 56. [CrossRef]
103. Morin Dalton, T. An approach for integrating economic impact analysis into the evaluation of potential marine protected area sites. *J. Environ. Manag.* **2004**, *70*, 333–349. [CrossRef]

104. Hornborg, S.; Hobday, A.J.; Ziegler, F.; Smith, A.D.M.; Green, B.S. Shaping sustainability of seafood from capture fisheries integrating the perspectives of supply chain stakeholders through combining systems analysis tools. *ICES J. Mar. Sci.* **2018**, *75*, 1965–1974. [CrossRef]
105. Xuan, B.B.; Armstrong, C.W. Trading Off Tourism for Fisheries. *Environ. Resour. Econ.* **2019**, *73*, 697–716. [CrossRef]
106. Ban, N.C.; Gurney, G.G.; Marshall, N.A.; Whitney, C.K.; Mills, M.; Gelcich, S.; Bennett, N.J.; Meehan, M.C.; Butler, C.; Ban, S.; et al. Well-being outcomes of marine protected areas. *Nat. Sustain.* **2019**, *2*, 524–532. [CrossRef]
107. Mangubhai, S.; Wilson, J.R.; Rumetna, L.; Maturbongs, Y.; Purwanto. Explicitly incorporating socioeconomic criteria and data into marine protected area zoning. *Ocean Coast. Manag.* **2015**, *116*, 523–529. [CrossRef]
108. Wilhelm, T.A.; Sheppard, C.R.; Sheppard, A.L.; Gaymer, C.F.; Parks, J.; Wagner, D.; Lewis, N.A. Large marine protected areas–advantages and challenges of going big. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2014**, *24*, 24–30. [CrossRef]
109. Leenhardt, P.; Cazalet, B.; Salvat, B.; Claudet, J.; Feral, F. The rise of large-scale marine protected areas: Conservation or geopolitics? *Ocean Coast. Manag.* **2013**, *85*, 112–118. [CrossRef]
110. Gleason, M.; McCreary, S.; Miller-Henson, M.; Ugoretz, J.; Fox, E.; Merrifield, M.; McClintock, W.; Serpa, P.; Hoffman, K. Science-based and stakeholder-driven marine protected area network planning: A successful case study from north central California. *Ocean Coast. Manag.* **2010**, *53*, 52–68. [CrossRef]
111. Halpern, B.S.; Lester, S.E.; McLeod, K.L. Placing marine protected areas onto the ecosystem-based management seascape. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 18312–18317. [CrossRef]