Dynamic Ocean Management: Integrating Scientific and Technological Capacity with Law, Policy, and Management

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The ocean is a dynamic environment with ocean currents and winds moving surface waters across large distances. Many animals that live in the ocean, particularly in offshore regions, are mobile in space and in time, as are most human users. Spatial management responses have typically partitioned the ocean into different regions with fixed management boundaries. In some regions a particular activity may be forbidden, in another it may be permitted but regulated, and in others it may be allowed without any regulation. In contrast, dynamic ocean management (DOM) changes in space and time in response to the shifting nature of the ocean and its users. DOM techniques have been applied in a limited number of situations around the world—notably for fisheries—to regulate or restrict the capture of a particular marine species. DOM requires scientific, technological, management, legal, and policy capacity across a range of elements. The article outlines seven of these elements and describes requirements and challenges for their implementation. Specifically, the elements considered are: (1) tools and data collection, (2) data upload and management, (3) data processing, (4) data delivery, (5) decision-making, (6) implementation, and (7) enforcement. Not all elements may be required and not all management, policy, and legal issues will be relevant to all applications. However, these elements represent major considerations in the application of DOM. Overall, we find that the scientific and technological capacity for DOM is strong but there are a range of underutilized policy applications. We give examples of how these policies could be expanded to provide for a broader application of dynamic ocean management. There are distinct regional variations in the capacity to implement these elements whether on a voluntary or compulsory basis. To use DOM effectively, the science and technology required for DOM needs to be better integrated with the enabling policy.

I. INTRODUCTION

The ocean is a dynamic environment with currents, winds, and temperatures changing over a range of time and space scales. Fish, seabirds, marine mammals, turtles, and most human users respond to this varying environment by seeking or following favorable conditions on daily, seasonal, and annual timeframes. Intrinsic inclusion of the dynamic nature of the ocean and of the interactions between dynamic human activities and marine resources in management has given rise to a new form of management, dynamic ocean management. We define dynamic ocean management (DOM) as management that changes in space and time in response to the shifting nature of the ocean and its users based on the integration of current biological, oceanographic, social, and/or economic data. We argue that DOM is a valuable complement to existing static management approaches because the human-environmental system we are attempting to manage is dynamic, and that DOM is particularly useful in developed countries where technological advances enhance effectiveness. DOM provides an alternative approach that can overcome some problems found with coarse-scale, fixed spatial management of marine species.[1]

To date, DOM approaches have been used in offshore surface waters to manage marine species affected by human activities such as bycatch.[2] But DOM's application could extend to a broad array of human activities in the ocean including military operations, alternative energy sources (such as wind, solar, and tidal energy), and oil and gas production. DOM can take a number of forms. Fisheries management areas may change in space or time,[3] and marine protected areas may account for dynamic oceanographic processes, such as seasonal presence of fronts and eddies.[4] It may also incorporate non-spatial elements such as fishing quotas that vary over time.[5]

The DOM approach is attractive for a range of situations because its restrictions tend to be smaller in spatial extent than under static area management approaches, which reduces conflicts with other users. In particular DOM can reduce conflicts arising as a result of competing objectives in ocean management.[6] For instance, protecting mobile marine species with static management approaches may require restricting human activity across large

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1. *See* Hedley S. Grantham et al., *Accommodating Dynamic Oceanographic Processes and Pelagic Biodiversity in Marine Conservation Planning*, 6 PLOS ONE 1, 9 (2011) [hereinafter Grantham et al., *Dynamic Planning*] (noting that dynamic protected area systems could be used as an alternate approach to fixed-spatial protected areas for species whose recruiting and spawning areas changed with time).

2. *See* Alistair J. Hobday et al., *Seasonal Forecasting of Tuna Habitat for Dynamic Spatial Managemen*t, 68 CAN. J. FISHERIES & AQUATIC SCI. 898, 905-07 (2011) [hereinafter Hobday et al., *Seasonal Forecasting*]; Evan A. Howell et al., *TurtleWatch: A Tool to Aid in the Bycatch Reduction of Loggerhead Turtles* Caretta caretta *in the Hawaii-based Pelagic Longline Fishery*, 5 ENDANGERED SPECIES RES. 267, 275-76 (2008).

3. *See* Grantham et al., *Dynamic Planning*, *supra* note 1, at 2; Edward T. Game et al., *Dynamic Marine Protected Areas Can Improve the Resilience of Coral Reef Systems*, 12 ECOLOGY LETTERS 1336, 1337 (2009); Hedley S. Grantham et al., *Reducing Bycatch in the South African Pelagic Longline Fishery: The Utility of Different Approaches to Fisheries Closures*, 5 ENDANGERED SPECIES RES. 291, 296 (2008) [hereinafter Grantham et al., *Closures*"].

4. *See* INT'L UNION FOR CONSERVATION OF NATURE, ECOLOGICALLY OR BIOLOGICALLY SIGNIFICANT AREAS IN THE PELAGIC REALM: EXAMPLES & GUIDELINES 21 (Daniel C. Dunn et al eds., 2011); Edward T. Game et al., *Pelagic Protected Areas: The Missing Dimension in Ocean Conservation*, 24 TRENDS ECOLOGY & EVOLUTION 360, 364 (2009).

5. *See* Alistair J. Hobday & K. Hartmann, *Near Real-Time Spatial Management Based on Habitat Predictions for a Longline Bycatch Species*, 13 FISHERIES MGMT. & ECOLOGY 365, 365 (2006) (discussing fishing quotas used in a dynamic management system).

6. Objectives differ. Conservation objectives seek to protect species of concern, shipping objectives relate to fast and safe movement of goods, and fishing objectives relate to the efficient capture of target species.

areas.[7] DOM can provide comparable protection to such species by identifying smaller protected areas that move in response to predictable animal or oceanographic movements. As a result, restrictions on human activity are limited to smaller geographic areas and activities may continue in other areas without similar restrictions.

Legal capacity for DOM, however, is variable, and even voluntary DOM approaches face legal challenges due to data confidentiality and intellectual property protections. By definition, DOM is responsive to real-time changes in human factors (for example, fishing vessel movements) and environmental factors (for example, ocean temperatures). Compulsory applications of DOM particularly necessitate highly adaptable and rapid decision-making by regulators. Yet legal regimes typically favor processes resulting in decisions that grant resource users certainty. Traditionally, these processes incorporate user consultation and take place over time periods of months to years, creating a significant impediment for DOM applications.[8] Despite this, the few existing compulsory DOM applications have overcome these impediments successfully. We highlight how these impediments have been overcome in subsequent sections, and also discuss remaining challenges for voluntary and compulsory approaches.

Several well-known examples of DOM seek to reduce the overlap of fishing operations with the distribution of bycatch species. TurtleWatch, a voluntary program in the North Central Pacific, aims to reduce the bycatch of sea turtles in the Hawaii shallow-set longline fishery.[9] This scheme was developed to address the significant increase in the number of loggerhead turtles in the bycatch of the Hawaii-based longline fishery during the 1990s which led to temporary time-area closures in the early 2000s and eventually a ban of all shallow-set fishing in 2002.[10] The shallow-set fishery was reopened in late 2004 with significant restrictions, including a total take limit of seventeen interactions with

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7. *See* Grantham et al., *Closures*, *supra* note 3, at 29 (discussing potential restrictions, including gear restrictions, temporal restrictions, bycatch reduction devices, and closures).

8. *See, e.g.*, Alistair .J. Hobday et al., *Electronic Tagging Data Supporting Flexible Spatial Management in an Australian Longline Fishery*, *in* TAGGING AND TRACKING OF MARINE ANIMALS WITH ELECTRONIC DEVICES 393 (J. Nielsen, J.R. Sibert, A.J. Hobday & M.E. Lutcavage, H. Arriabalaga & N. Fragoa, eds., 2009) [hereinafter Hobday et al., *Tagging*] (discussing previous management decisions identifying southern bluefin tuna habitat based on many rounds of consultation).

9. Howell et al., *supra* note 2, at 267.

10. *Id.* at 268.

loggerhead turtles, after which the fishery would be closed for the rest of the year.[11] In March 2006, the seventeen-loggerhead-turtle-take limit was reached, forcing the closure of the shallow set portion of the fishery for the rest of the year.[12] The TurtleWatch program was subsequently developed to determine if areas of high turtle abundance could be identified and avoided by the fishery.[13] Operational longline fishery characteristics, bycatch information, and loggerhead turtle satellite tracks were used in conjunction with remotely sensed sea surface temperature data to identify the area where the majority of loggerhead turtle bycatch in the longline fishery occurred.[14] The TurtleWatch tool now provides a real-time map of the preferred thermal habitat of loggerhead sea turtles in the Pacific Ocean north of the Hawaiian Islands.[15] It allows fishers to voluntarily avoid regions where bycatch may be high, so as to avoid reaching the bycatch limit and hence shutting down the fishery, without imposing a fixed closed area.[16]

In eastern Australia, a longline fishery has used DOM since 2003 to reduce bycatch of southern bluefin tuna (SBT).[17] A quota-limited species, SBT makes annual winter migrations to the Tasman Sea off southeastern Australia.[18] During its migration, SBT interacts with a year-round tropical tuna longline fishery (Eastern Tuna and Billfish Fishery).[19] Fishery managers use spatial restrictions to minimize SBT bycatch by commercial longline fishers who have limited or no SBT quota.[20] They restrict access to areas in which SBT are believed to be present to fishers holding SBT quotas using a temperature-based habitat model to determine where SBT may be located.[21] To determine adult SBT temperature preferences, the model uses data from pop-up satellite archival tags.[22] The model provides near real-time SBT location information by matching these temperature preferences to satellite-based sea surface temperature data and to vertical

11. *Id.* at 269.
12. *Id.* at 268
13. *Id.*
14. *Id.* at 269-70.
15. *Id.* at 277.
16. *Id.* at 276.
17. Hobday et al., *Seasonal Forecasting*, *supra* note 2, at 898; *see also* Hobday & Hartmann, *supra* note 5, at 366.
18. Hobday & Hartmann, *supra* note 5, at 365.
19. *Id.*
20. *Id.*
21. *Id.*
22. *Id.* at 367.

temperature data from an oceanographic model, which is updated every two weeks during the overlap period.[23] Because the DOM zones vary in response to the distribution of fish habitat, areas smaller than the annual area under management are closed at any one time, reducing conflict with fishers.

Past articles have outlined the scientific and management process for these and other DOM examples.[24] This article identifies seven elements commonly encountered when seeking to implement DOM: (1) tools and data collection, (2) data upload and database management, (3) data processing, (4) data delivery, (5) decision-making, (6) implementation, and (7) enforcement.[25] This analysis is based on a review of current examples and considers the scientific, technological, management, and policy issues affecting each of these seven elements. The remainder of this article is organized into three Parts. In Part Two we briefly examine and describe each of the seven elements supporting DOM and consider current scientific/technological, legal, and institutional issues. We also highlight the current challenges to implementing each element and provide examples from the United States and Australia to illustrate effective uses of science and technology. In Part Three we identify policy and management needs to show how capacity to implement DOM might be increased. Finally, in Part Four we conclude that, though challenging, a dynamic approach to management is critical given the ever-changing nature of the marine system, its species, and its human users. We further argue that DOM increases both ecologic and economic sustainability of marine systems. Its success, however, requires strong institutional and stakeholder support.

II. SEVEN ELEMENTS SUPPORTING DYNAMIC OCEAN MANAGEMENT

In this Part, we describe seven critical elements needed to fully implement DOM.[26] While the first four elements may seem similar because they all relate to data, separating them is important since a focus on only one element generally has failed to support DOM. Voluntary DOM approaches may only need to consider these first

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23. Hobday et al., *Seasonal Forecasting*, *supra* note 2, at 899.

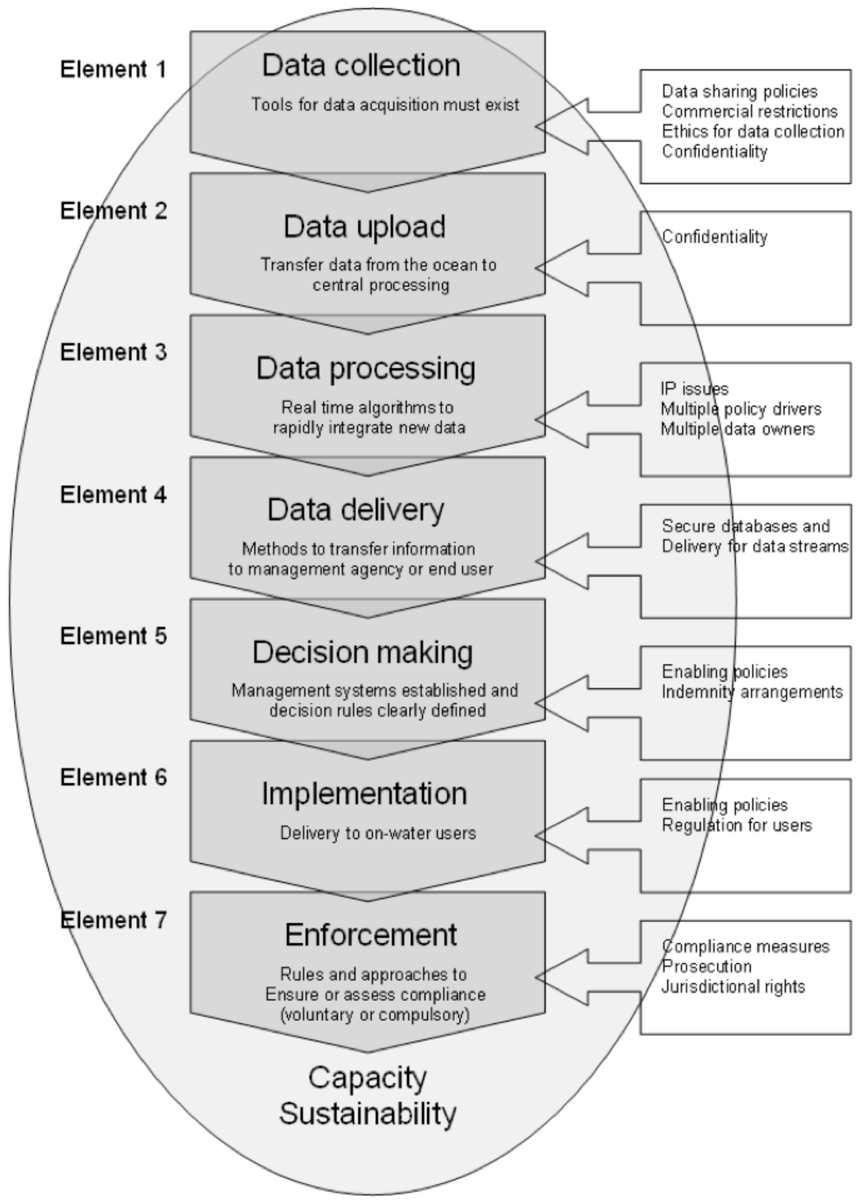
24. *See, e.g.*, Grantham et al., *Dynamic Planning*, *supra* note 1, at 2; INT'L UNION FOR CONSERVATION OF NATURE, *supra* note 4, at 7; Hobday et al., *Tagging*, *supra* note 8, at 381; K. David Hyrenbach, Karin A. Forney & Paul K. Dayton, *Marine Protected Areas and Ocean Basin Management*, 10 AQUATIC CONSERVATION: MARINE & FRESHWATER ECOSYSTEMS 437, 445-46 (2000).

25. *See infra* Figure 1.

26. *Id.*

four elements. Thus, the management, legal, and policy considerations relevant to these are discussed together. Compulsory DOM, enforced through legislation or policy, usually encompasses all seven elements. For the final three elements, the management, legal, and policy considerations are described immediately after each element.

Figure 1: Scientific and Technological Elements that Contribute to Effective DOM



* Scientific and technological elements (**gray boxes)**; examples of the legal, policy, and management issues that affect the depolyment of the technological solution (**white boxes**). Voluntary DOM may only follow the first four elements, while compulsory DOM typically requires all seven elements. Overarching issues of capacity and system sustainability also may constrain DOM.

A. *Element 1: Data Collection: Scientific and Technological Issues*

Data collection is the first step toward developing information to support DOM.[27] To develop the information needed to support DOM decision-making, it is necessary to combine and synthesize oceanographic, biological, and resource use data.[28] To inform predictive models, data collection for DOM thus necessarily spans a wide range of data sources, technologies, and collection activities.[29] DOM can require continuous data input to provide information on the state of a marine ecosystem at a particular time and information regarding recurring patterns across space and time.[30]

Most DOM examples require the input and processing of remotely or directly sensed oceanographic observations collected at regional and global scales in real or near real time.[31] Such data allow scientists to assess the temporal dynamics of oceanographic variables, including sea surface temperature (SST), ocean color (chlorophyll-a), currents, and other variables.[32] These data are generally processed into either instantaneous values for a specific observation period or aggregated into spatial climatologies that represent expected conditions for average seasonal or monthly time periods.[33] Direct observations for a specific date or time period are useful for monitoring specific conditions and relationships, while remotely sensed climatological datasets provide baselines for the expected periodicity of ocean processes, for example, their seasonal cycles.[34]

In situ biological or resource use data are necessarily more spatially restricted and expensive to collect than remotely sensed oceanographic data.[35] Biological data can be collected from a range of sources, including fishers, observers, and electronic tags. Existing DOM systems most often use biological data from

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27. *See* John H. Roe et al., *Predicting Bycatch Hotspots for Endangered Leatherback Turtles on Longlines in the Pacific Ocean*, 281 PROC. ROYAL ACAD. B 1, 2 (2014).
28. *Id.* at 6.
29. *Id.* at 2.
30. *Id.* at 2.
31. *Id.* at 6.
32. *Id.*
33. *See* Dana K. Wingfield et al., *The Making of a Productivity Hotspot in the Coastal Ocean*, 6 PLOS ONE 1, 3 (2011) (discussing oceanographic features that lead to aggregation of foraging loggerhead turtles).
34. *Id.* at 4-5 (discussing direct observations and remote sensing-based data gathering techniques).
35. Of course, satellites are more expensive than any tags. However, users do not pay the true cost of such remotely sensed data.

electronic tags.[36] However, DOM also may be supported by data collected from a wide variety of benthic and water column sampling methods, including visual observers, net trawls, Autonomous Marine Vehicles (AMV), surveys, genetic barcodes, passive acoustic monitoring, and telemetry tracking techniques.[37] DOM requires repeated measurements of biological data across multiple space and time scales to capture the expected ranges and periodicity of responses to oceanographic variability.

Because DOM is often linked to movements of highly mobile species, we will discuss several particularly critical types of biological data collection methods. Satellite telemetry, active acoustic sensors, and passive acoustic monitoring track the movements and behavior of individual animals in relation to changing oceanographic conditions.[38] This type of direct spatio-temporal monitoring measures animal movements, physiological conditions, and three-dimensional dive behavior, giving valuable information on animal responses to natural and anthropogenic changes in their environment.[39] Some tracking devices, especially those that can transmit data in real time, are more appropriate for use with dynamic management, and those that also provide oceanographic data may be particularly useful.[40] However, not all devices are suitable for all species, particularly for smaller species or for species that broach the surface infrequently. Argos satellite tags provide at-sea locations and have the advantage that the data can be recovered remotely.[41] Electronic tags deployed on animals also provide oceanographic data in areas where conventional methods are limited or absent.[42]

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36. *See* Hobday et al., *Tagging*, *supra* note 8, at 381; Howell et al., *supra* note 2, at 268.

37. *See* ARCTIC COUNCIL, ARCTIC MARINE BIODIVERSITY MONITORING PLAN: CAFF MONITORING SERIES REPORT NO. 3 at 36, 53-56, 62 (2011). AMVs may provide particularly high-quality data in both surface and subsurface marine environments especially relative to often-used technologies like radio signals and sonar, both of which are limited by short-range frequencies. The data can be collected and transmitted in real time for analysis and further sampling at either the same or alternative locations.

38. Daniel P. Costa et al., *New Insights into Pelagic Migrations: Implications for Ecology and Conservation*, 43 ANN. REV. ECOLOGY, EVOLUTION & SYSTEMATICS 73, 77-80 (2012) [hereinafter Costa et al., *New Insights*].

39. *Id.* at 84.

40. *See infra* Table 1; *see also* Costa et al., *New Insights*, *supra* note 38, at 79; Elliot Hazen et al., *Ontogeny in Marine Tagging and Tracking Science: Technologies and Data Gaps*, 457 MARINE ECOLOGY PROGRESS SERIES 221, 231-33 (2012).

41. Costa et al., *New Insights*, *supra* note 38, at 79-80.

42. L. Boehme et al., *Animal-Borne CTD-Satellite Relay Data Loggers for Real-Time Oceanographic Data Collection*, 5 OCEAN SCI. 685, 687-89 (2009); J.-B. Charrassin et al., *Southern Ocean Frontal Structure and Sea-Ice Formation Rates Revealed by Elephant Seals*, 105 PROC. NAT'L ACAD. SCI. 11,634, 11,636-37 (2008); Daniel P. Costa et al., *Approaches to*

Table 1: Comparison of Devices Currently Available and Commonly Used for Tracking Marine Species.

Tracking method	Accuracy	Data recovery	Use in DOM
Global Positioning System (GPS) loggers	High (m)	Device recovery necessary	Historical description of ocean use
Platform Terminal Transmitters (PTT)	Medium (few km)	Real-time data downloaded via satellite	Real-time integration of data streams
Argos/GPS-PTT	High (m)	Real-time data downloaded via satellite	Real-time integration of data streams
Very High Frequency (VHF) radio tags	Medium (few km)	Real-time collection of data at site	Historical description of ocean use
Geolocators (GLS) and archival tags – loggers	Low (>100 km)	Device recovery necessary	Historical description of ocean use
Compass – loggers	Medium (few km)	Device recovery necessary	Historical description of ocean use

* The accuracy and method of data recovery are particularly pertinent to dynamic ocean management. Adapted from Lascelles et al. 2012.[43]

Data on species presence or absence provide information on the species' expected distribution range, biogeographic patterns, and biological diversity. However, to address many of the questions underpinning DOM, repeated observations of species abundance and density are essential.[44] These questions include how populations change across naturally occurring variations in ocean conditions and how human use patterns change.[45] A number of different data types can be used to inform these questions including data collected by aerial or at-sea survey programs, fishery-independent sampling surveys, and benthic habitat dive surveys.

Equally critical to biological data collection is resource use data, including the distribution of users, type of activity, and intensity of use in space and time. Significant advances in the development of vessel tracking systems such as automatic

Studying Climatic Change and Its Role on the Habitat Selection of Antarctic Pinnipeds, 50 INTEGRATIVE & COMP. BIOLOGY 1018, 1019 (2010) [hereinafter Costa et al., *Pinnipeds*].

43. Ben G. Lascelles et al., *From Hotspots to Site Protection: Identifying Marine Protected Areas for Seabirds Around the Globe*, 156 BIOLOGICAL CONSERVATION 5, 7 (2012).

44. Rob Williams et al., *Prioritizing Global Marine Mammal Habitats Using Density Maps in Place of Range Maps*, 56 ECOGRAPHY 1, 58 (2013).

45. Sarah M. Maxwell et al., *Cumulative Human Impacts on Marine Predators*, 4 NATURE COMM. 1, 4-5 (2013).

identification systems (AIS) and vessel monitoring systems (VMS) now allow for near-real-time tracking of shipping and fishing vessels in the oceans.[46] These data provide critical information on the spatio-temporal distribution of users but may not provide enough details on intensity of use or specific activities, for example, the quantity of commercial species harvested, and type of activity occurring. Data on activity type and use intensity are frequently collected via on-board observers or through voluntary reporting systems, for example, through fishery logbook reporting, one-to-one interviews, and email.[47] However, some of these data collection systems may result in time lags that exceed DOM needs. Technological advances, such as smartphone applications that allow for near-real-time reporting may address this problem. For example, eCatch is a smart device application that allows fishers to collect and input catch data and have it sent to a centralized database via cellular or satellite signals.[48]

B. *Element 2: Data Upload and Management: Scientific and Technological Issues.*

Following collection of the oceanographic, biological, and resource use data to be used in the DOM approach, data must be delivered, then rapidly compiled and integrated into a central location for processing (Element 3). In the case of oceanographic products such as gridded satellite-derived ocean temperatures, data can be obtained from a number of primary sources and housed locally or accessed online when needed. For example, at Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), a series of computer programs automatically updates and maintains a file system of oceanographic data products used for DOM, including gridded datasets of temperature and chlorophyll, making the data accessible in real time.[49]

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46. *See* Erik Jaap Molenaar & Martin Tsamenyi, *Satellite-based Vessel Monitoring Systems for Fisheries Management: International Legal Aspects*, 15 INT'L. J. MARINE & COASTAL L. 65, 65, 80 (2000).

47. *See, e.g.*, Derek J. Hamer, Tim M. Ward & Richard McGarvey, *Measurement, Management and Mitigation of Operational Interactions Between the South Australian Sardine Fishery and Short-beaked Common Dolphins (*Delphinus delphis*)*, 141 BIOLOGICAL CONSERVATION 2865, 2873 (2008) (describing data collection using fishery logbooks).

48. *See eCatch*, THE NATURE CONSERVANCY, https://www.ecatch.org/Media/about.htm (last visited Apr. 3, 2014).

49. See Jason R. Hartog et al., *Developing Integrated Database Systems for the Management of Electronic Tagging Data*, *in* TAGGING AND TRACKING OF MARINE ANIMALS WITH

A range of data upload technologies exist for data collected at sea, including biological data, such as tag-based location data, and resource use data, such as fishing vessel location data. These include satellite-based (ARGOS), telephone-based (Iridium), telemetered and transmitted (acoustic), radio transmission (catch records), and traditional email and web-based technologies (vessel or observer reports).[50] Additionally, some data cannot be transmitted but rather must be stored and directly downloaded from the device either at a single time (for example, archival-based tags), or on a regular basis when instruments are serviced.[51]

While some data are ready to use once transmitted, other types require additional processing. For example, location information can be obtained from archival data logging tags that collect light-level data from which geographic positions can be reconstructed based on day length and on-board clock offsets.[52]

GPS tags provide the highest quality tracks in terms of both spatial and temporal resolution for marine species. The most recent GPS tags acquire satellite signals and either store them for later calculation after tag recovery or use them to calculate average position for a specified time period that can then be transmitted via Argos.[53] Even with these techniques, however, Argos bandwidth still limits the amount of information that can be transmitted, with only a small fraction of collected GPS locations typically being transmitted. All of the data can be recovered from GPS tags if the tag is retrieved or it is linked to cell phone networks, but this requires that the animals, such as seals, haul out within the range of wireless telecommunication networks.[54] Acoustic pingers have seen the broadest application for non-surfacing species and have been deployed on both invertebrates and vertebrates. These tags are generally implanted into the animal and produce a unique

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ELECTRONIC DEVICES 374 (J. Nielsen, J.R. Sibert, A.J. Hobday & M.E. Lutcavage, H. Arriabalaga & N. Fragoa, eds., 2009).

50. *See, e.g.*, Marco Marcelli et al., *New Technological Developments for Oceanographic Observations*, *in* OCEANOGRAPHY 44-45, 54, 60 (Marco Marcelli, ed. 2012) (referencing ARGOS, Iridium, acoustic data gathering methods, data transmission, and observations).

51. Michael K. Musyl et al., *Ability of Archival Tags to Provide Estimates of Geographic Position Based on Light Intensity, in* ELECTRONIC TAGGING AND TRACKING IN MARINE FISHERIES 346 (John R. Sibert & Jennifer R. Nielsen, eds. 2001).

52. David W. Welch & J. Paige Eveson, *An Assessment of Light-Based Geoposition Estimates from Archival Tags*, 56 CAN. J. FISHERIES & AQUATIC SCI. 1317, 1326 (1999).

53. Stanley M. Tomkiewicz et al., *Global Positioning System and Associated Technologies in Animal Behaviour and Ecological Research*, 365 PHIL. TRANSACTIONS ROYAL SOC'Y B: BIOLOGICAL SCI. 2163, 2166 (2010).

54. Bernie McConnell et al., *Phoning Home–A New GSM Mobile Phone Telemetry System to Collect Mark-Recapture Data*, 20 MARINE MAMMAL SCI. 274, 279 (2004).

coded acoustic ping that can be tracked with a fixed or mobile acoustic receiver array.[55] Data from the devices are automatically downloaded from mobile or moored listening stations, or can be collected when moored stations are recovered.[56]

Security from database failure is also an issue for DOM. Systems failure will lead to a breakdown in delivery of processed information to the users. Backup and storage of databases and raw data is recommended, typically on two systems or with two user accounts. With the CSIRO data management system, for example, all transmission data available for an Argos program are stored in a different user account that is routinely backed up.[57] In this way, all the raw, unprocessed data from Argos are maintained should either the database or the database backup fail. In the unlikely event the database or decoding has been corrupted, the whole system can be restored quickly using only the raw Argos downloads. Similar data security systems are in place for the Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP), a global biogeographic data commons for tracking and survey data of large marine vertebrates.[58]

C. *Element 3: Data Processing: Scientific and Technological Issues.*

DOM products, such as habitat maps, are generated from a combination of data types. Real-time data are crucial for identifying oceanographic variability or any sudden or short-term population shifts that may require a change in protected area boundaries on a short time scale. Such a situation may arise, for example, when a species of concern interacts with a human activity, for example, a right whale being present in a shipping lane.[59] Thus, retrospective approaches to data processing likely are

55. Laurent Dagorn et al., *Satellite-Linked Acoustic Receivers to Observe Behavior of Fish in Remote Areas*, 20 AQUATIC LIVING RES. 307, 308-09 (2007); M.R. Heupel et al., *Automated Acoustic Tracking of Aquatic Animals: Scales, Design and Deployment of Listening Station Arrays*, 57 MARINE & FRESHWATER RES. 1, 8-10 (2006).

56. *See supra* Table 1.

57. Hartog et al, *supra* note 49, at 371-74 (describing potential to store ARGOS data in central database and with individual clients).

58. P.N. Halpin et al., *OBIS-SEAMAP: Developing a Biogeographic Research Data Commons for the Ecological Studies of Marine Mammals, Seabirds, and Sea Turtles*, 316 MARINE ECOLOGY PROGRESS SERIES 239, 242-44 (2006).

59. *See, e.g.*, Sofie M. Van Parijs et al., *Management and Research Applications of Real-Time and Archival Passive Acoustic Sensors Over Varying Temporal and Spatial Scales*, 395 MARINE ECOLOGY PROGRESS SERIES 21, 24 (2009) (discussing the problem of ships striking whales).

inadequate for supporting real-world DOM.

Obtaining real-time biological data may require, for instance, automated processing of animal tracking data in comparable or standardized formats. To automatically download, decode, and archive tag data from Service Argos on a daily basis, control scripts may be required.[60] For example, the CSIRO Electronic Tag Database collates data from satellite tags and pop-up satellite archival tags via a fully automated system driven by a series of functions and scripts executed in both Perl and Bash in a Linux environment.[61]

Complex information needs to be combined in a software product with an analysis framework that is adaptable and able to incorporate incoming data. For example, satellite tag data often need to be processed through state space modelling or other filters.[62] By contrast, "sightings data" (for example, information about whale positions) needs to be converted to spatial densities.[63] In most cases, oceanographic information is then combined with biological information via customized software to generate habitat maps that support dynamic management decision-making.[64] In addition to custom software packages, web-based tools such as the Satellite Tracking and Analysis Tool (STAT) can provide track standardization and can sample environmental data.[65] Tools in programming languages such as MATLAB and R include Xtractomatic,[66] and the Marine Geospatial Analysis Tools (MGET) in ArcGIS[67] can be used to combine point data with environmental features. This data combination is a necessary step in

60. *Id.*

61. Hartog et al, *supra* note 49, at 371.

62. *See, e.g.*, Costa et al., *New Insights supra* note 38, at 81; Arliss J. Winship et al., *State-space Framework for Estimating Measurement Error from Double-Tagging Telemetry Experiments*, 3 METHODS ECOLOGY & EVOLUTION, 291, 291 (2011); Greg A. Breed et al., *Sex-specific, Seasonal Foraging Tactics of Adult Grey Seals (*Halichoerus Grypus*) Revealed by State-space Analysis*, 90 ECOLOGY 3209, 3209 (2009).

63. *See Distance – An R Package for Distance Sampling Analysis,* GITHUB, https://github.com/dill/Distance/wiki (last visited Mar. 30, 2014) (providing a tool for converting spatial densities).

64. *See, e.g.*, Hobday & Hartmann, *supra* note 5, at 366.

65. *See* M. S. Coyne & B. J. Godley*, Satellite Tracking and Analysis Tool (STAT): An Integrated System for Archiving, Analyzing and Mapping Animal Tracking Data*, 301 MARINE ECOLOGY PROGRESS SERIES 1, 1 (2005) (describing use of STAT).

66. *See* J. S. Stewart et al., *Marine Predator Migration During Range Expansion: Humboldt Squid Dosidicus Gigas in the Northern California Current System*, 471 MARINE ECOLOGY PROGRESS SERIES 135, 140 (2012) (discussing use of Xtractomatic)

67. *See* Jason J. Roberts et al., *Marine Geospatial Ecology Tools: An Integrated Framework for Ecological Geoprocessing with ArcGIS, Python, R, MATLAB, and C++*, 25 ENVTL. MODELLING. & SOFTWARE 1197, 1197 (2010) (discussing use of MGET in ArcGIS).

understanding the species-environment relationships that underlie DOM frameworks. Ultimately, automated processing of multiple data types will be necessary to provide a DOM product that can be used by managers and resource users in near real time.[68]

D. *Element 4: Data Delivery: Scientific and Technological Issues.*

Delivering data back to a user in real or near real time is critical for DOM to operate over short time scales. Data may be provided to management agencies or resource users, or it may be processed for a specific management application and then made publicly available.[69] A number of data delivery systems already exist, ranging in level of sophistication and specificity.

Email and websites are two of the most common delivery systems for processed data, particularly remote-sensing systems. For example, the Argos satellite system uses email as a base delivery system for data such as animal and vessel location.[70] Users can log on to websites to access data in more sophisticated forms. On the northeastern coast of the United States, the Yellowtail Bycatch Avoidance Program aims to minimize bycatch of yellowtail flounder in the scallop fishery.[71] It uses email to collect data from fishers regarding the distribution of yellowtail flounder bycatch in the scallop fishery and to distribute the next day's recommendations on which areas to avoid.[72] Similarly, in Australia, researchers deliver forecasts of SBT habitat by email to fisheries managers so that zones can be created for fishers based on the amount of SBT quota they hold.[73] Managers then alert fishers through messages via VMS sent to all vessels with email. Web-based updates are also provided. Finally, TurtleWatch uses a website to provide weekly maps indicating areas that fishers should consider avoiding to reduce loggerhead turtle bycatch.[74]

More complex data delivery systems for specific data types or programs allow users to interact with the information provided.

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68. *See* Hobday et al., *Seasonal Forecasting*, *supra* note 2, at 908-09.

69. *See* Howell et al., *supra* note 2, at 272-73 (describing changes in turtle bycatch after data was processed and made publicly available through the TurtleWatch system).

70. *See* Costa et al., *New Insights*, *supra* note 38, at 78-80 (describing how data is transmitted through the Argos system).

71. *See Bycatch Avoidance Programs*, UMASS DARTMOUTH SCHOOL FOR MARINE SCIENCE & TECHNOLOGY, http://www.umassd.edu/smast/bycatch/ (last visited Mar. 31, 2014).

72. *Id.*

73. Hobday et al., *Seasonal Forecasting*, *supra* note 2, at 908.

74. *See* Howell et al., *supra* note 2, at 270 (describing weekly compilation of data to create maps available through the Pathfinder V4 SST product).

For example, wildlifetracking.org, a service of seaturtle.org, serves data from nearly 3,000 active satellite-tracked animals.[75] When used with STAT and with bathymetry or remote sensing data, users can filter, analyze, and map satellite tracks.[76] Other similar systems include Movebank,[77] OzTrack,[78] and seabirdtracking.org.[79] Smart phones also are being used to deliver data using apps like eCatch, a program developed by The Nature Conservancy to input, track, and serve data for fishers on the west coast of the United States.[80] While many apps, such as the Global Shark Tracker app, are currently used as outreach tools, they also can be used to serve information directly to users.[81] For example, fishery observers could input data using an app. This same app could then process and serve the information back to fishers with relevant regulations, such as closed areas or quota restrictions.[82] VMS also can be used to confirm that fishers received the most up-to-date spatial regulations.

1. *Legal and management challenges associated with data collection and management systems*

The data-related components of DOM described in elements one through four present both management and legal challenges. These include issues related to confidentiality, data sharing, ownership and intellectual property rights, use of autonomous marine vehicles, and animal ethics, as discussed below.

2. *Privacy and confidentiality*

Privacy and confidentiality impinge on the use of data for DOM and present distinct legal challenges in different countries. Data uploading must comply with any privacy agreements or codes.

Confidentiality policies and laws protect the commercial and

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75. *See* WILDLIFE TRACKING, http://www.wildlifetracking.org/ (last visited Mar. 31, 2014).

76. Coyne & Godley, *supra* note 65, at 1-2.

77. *See* B. Kranstauber et al., The *Movebank Data Model for Animal Tracking*, 26 ENVTL. MODELLING & SOFTWARE 834, 834 (2011).

78. P. Newman et al., *Oztrack: Data Management and Analytics Tools for Australian Animal Tracking*, 5 ERESEARCH AUSTL. CONF. 1, 1 (2011).

79. *Seabird Tracking Database*, BIRDLIFE INT'L, http://seabirdtracking.org (last visited Mar. 31, 2014).

80. *See* THE NATURE CONSERVANCY, *supra* note 48.

81. *See* OCearch, *Global Shark Tracker*, ITUNES (last updated Jan. 20, 2014), https://itunes.apple.com/us/app/global-shark-tracker/id570772231?mt=8.

82. *See, e.g.*, *Powered by Conserve.iO*, CONSERVE.IO, http://conserve.io/showcase/ (last visited Mar. 31, 2014) (listing available "spotter" and "alert" apps).

privacy rights of resource permit holders.[83] For example, to protect information regarding the locations of fishers' preferred fishing grounds, fishing data in the United States must be aggregated so that vessel movement and catch information about each fishing gridcell may only be released if more than three vessels have used the gridcell.[84] Australia requires that at least five vessels use an area before reporting of data at a one-degree scale is permitted.[85]

The availability of data regarding activities in the Exclusive Economic Zone varies from jurisdiction to jurisdiction. For example, in the United States, the National Marine Fisheries Service (NMFS) Catch Share Program monitors how the economic benefits and distribution of trawl fishing change over time, and produces a publicly available annual report that highlights aggregate economic data for trawl fishery participants.[86] The report is generated based on submissions from these participants, including data regarding vessel and processing plant characteristics, capitalized investments, annual expenses, annual earnings, crew and labor payments, and quota and permit expenses.[87] Individual submissions are confidential under the Magnuson-Stevens Act (MSA) and National Oceanic & Atmospheric Administration (NOAA) Administrative Order 216-100.[88] Individual fishers' information is added to a common fishery database, and fishers retain privacy regarding individual fishing techniques and preferred fishing grounds. Regulatory agencies, scientists, and fisheries managers can then use the data while

83. *See, e.g.*, Miss. Code R. § 22—1—24:03 (recognizing the confidentiality of all data submitted to government officials through marine fisheries statistical reporting program).

84. *See* 50 C.F.R. § 600.1014(h) (authorizing National Marine Fisheries' Service to aggregate data to preserve confidentiality).

85. AUSTL. FISHERIES MGMT. AUTH., FISHERIES MANAGEMENT PAPER 12: INFORMATION DISCLOSURE 4 (June 2010), *available at* http://www.afma.gov.au/wp-content/uploads/2010/07/fmp12.pdf?9370a8.

86. *See Catch Shares,* NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, http://www.nmfs.noaa.gov/sfa/management/catch_shares/index.html (last visited Mar. 31, 2014).

87. 50 C.F.R. § 660.114(a); (requiring submission of data); *see also Economic Data Collection (EDC) Overview,* NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, http://www.nwfsc.noaa.gov/research/divisions/fram/economic/overview.cfm (describing EDC program).

88. 16 U.S.C. § 1181a(b) (describing confidentiality requirements for data submitted under the MSA); NAT'L OCEANIC & ATMOSPHERIC ADMIN., ADMINISTRATIVE ORDER 216-100 at App. M (1994), *available at* http://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-100.html (providing for protection of confidential fisheries statistics).

protecting the identity of the fisher.[89] NMFS in 2012 sought to amend regulations under the MSA to further limit existing availability of fisheries information,[90] a proposal that met with strong opposition from environmental and conservation NGOs.[91] These restrictions on data accessibility can hinder DOM applications by making it difficult to accurately access economic trade-offs associated with proposed DOM activities.[92] Similar difficulties also apply to non-dynamic management applications.

State governments in the United States also have made fisheries data confidential. For example, Mississippi regulators collect information on seafood landed and processed in the state but are not allowed to divulge information provided unless it is in aggregate form or specific authorization has been given.[93] Mississippi's confidentiality protections are legitimized under the auspices of protection, conservation, and effective regulation of all seafood landed or processed within the state's territorial jurisdiction.[94] However, such regulations severely limit the circumstances under which state officials can reveal proprietary information to state or federal agencies and requires confidentiality officers to oppose other agency and congressional subpoenas.[95]

While businesses may have valid confidentiality concerns in providing catch share data, making this information confidential severely limits the utility of the data collected. Limiting data access could work against the interests of both fishers and conservationists, depending on the political climate. Without detailed information, policymakers may adopt an overly precautionary approach that would exclude fishers from contested grounds. Alternatively, negative effects may be overlooked with

89. *Cf.* Method of Data Collection for Fisheries Management. U.S. Patent Application WO2000052611 A2 (filed Nov. 23, 1999), *available at* http://www.google.com/patents/WO2000052611A2?cl=en (describing method of submitting commercial fishing data that protects identity of individual fishers).

90. Confidentiality of Information; Magnuson-Stevens Fishery Conservation and Management Reauthorization Act, 77 Fed. Reg. 30,486, 30,487 (May 23, 2012).

91. *See, e.g.*, Letter from Ivy Fredrickson, Staff Attorney, Ocean Conservancy, et al., to Karl Moline and Alan Risenhoover, Acting Deputy Administrator for Regulatory Programs, National Marine Fisheries Service (Oct. 19, 2012), *available at* http://www.pewenvironment.org/uploadedFiles/PEG/Publications/Other_Resource/Data%20Confidentiality%20Sign-on%20Letter%20pdf%20pdf.pdf (letter on behalf of more than fifty NGOs protesting proposed rule).

92. *See infra* Figure 2.

93. Miss. Code R. § 22—1—24:03

94. *Id.* § 22—1—24:02.

95. *Id.* § 22—1—24:03.

adverse outcomes for resource and biodiversity conservation.[96] Such confidentiality measures also run counter to trends in the United States, European Union, and elsewhere toward greater transparency and access to environmental information[97] and a commitment to implementing an ecosystem-based approach to fisheries management.[98] While the desire to make data anonymous may be legitimate, preventing scientific access to anonymous, individualized data is not. To date, scientists and other data users report general trends, not individual information.[99] Anonymous but individualized data would allow those interested in the data to conduct analyses based on individual users while protecting the identity of individual fishers. Data users could be required to sign data use agreements to this effect, as in Australia when raw fishing data is distributed beyond government and industry users.[100] For these reasons, confidentiality protections afforded in current laws, licences, permits, or quota conditions must be re-evaluated in light of DOM's emerging needs.

3. *Ownership and intellectual property rights*

Data ownership and intellectual property (IP) rights present significant data access, comprehension, and use challenges, particularly regarding difficult-to-collect tracking data.

In the United States, data collection and uploading may be subject to IP restrictions. If individuals (for example, recreational fishers) own the data, they may be able to restrict both access to and use of it. However, the MSA deems all resources in a fishery to be common property and prevents the individual ownership of such resources.[101] For some researchers collecting biological data, data ownership-particularly difficult-to-collect animal tracking data-presents concerns. Widespread distribution of such data, via websites and apps, needs to be done in a way that protects the researcher's IP interest in the data.

96. H. Hinz et al., *Confidentiality over Fishing Effort Data Threatens Science and Management Progress*, 14 FISH & FISHERIES 110, 116 (2012).

97. *See, e.g.*, Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters, *opened for signature* June 25, 1998, 2161 U.N.T.S. 447 (entered into force Oct. 20, 2001).

98. Hinz et al., *supra* note 96, at 110.

99. *Id.* at 113.

100. AUSTL. FISHERIES MGMT. AUTH., *supra* note 85, at 4.

101. Christopher Costello & Corbett A. Grainger, *The Value of Secure Property Rights: Evidence From Global Fisheries* 5 (Nat'l Bureau of Econ. Res., Working Paper No. 17019, May 2011), *available at* http://www.nber.org/papers/w17019.pdf?new_window=1.

While some funding agencies require that scientific data be publicly available, there are still considerable issues ensuring scientists comply with such requirements. Many data websites, such as wildlifetracking.org, seabirdtracking.org, and OBIS-SEAMAP, require visitors to agree to terms of use before they may access the data.[102] These terms of use typically require contacting the data custodian for permission to use the data. Permission must be sought each time new data are added to the repository. This creates difficulties for real time use of data for DOM, but standing agreements for real-time portals could overcome these difficulties with relative ease.

Additionally, modelled DOM products that integrate across datasets may address the needs of resource users, scientists, and managers alike and may aid in facilitating agreements to use data products in real time. Multi-dataset or modelled products protect an individual's data by smoothing and predicting individual datasets based on covariates, such that each vessel's location or each track is equally weighted in the final products. While feasible to use in DOM applications, multi-dataset or modelled products can take time to produce. Once created, however, real time data can be integrated into existing models.

Obtaining data from certain data streams, including satellite products such as temperature and chlorophyll from SeaWiFS and MODIS, also may involve legal barriers.[103] The data are sometimes used under research arrangements that prohibit data transfer to third parties as direct products. However, this barrier may be overcome by converting data streams to habitat maps or other data presentation formats. CoastWatch, a web service provided by NOAA that serves satellite data, has taken this approach to successfully overcome these barriers.[104]

In addition to technical and legal challenges, policy and institutional factors can promote or impede the integration of data from various sectors, agencies, and levels of government. However, structures and strategies for agency cooperation and coordination can maximize the use of DOM by allowing information to be integrated within and between local, national, and even regional

102. *See, e.g.*, *OBIS-SEAMAP Terms of Use*, OBIS-SEAMAP, http://seamap.env.duke.edu/about/termsofuse (last visited Mar. 31, 2014).

103. *See Welcome to the Ocean Productivity Home Page*, OCEAN PRODUCTIVITY, http://www.science.oregonstate.edu/ocean.productivity/ (last visited Mar. 31, 2014) (offering SeaWiFS and MODIS model and sensor products).

104. *See Coastwatch Browser*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., http://coastwatch.pfeg.noaa.gov/coastwatch/CWBrowser.jsp (last visited Mar. 31, 2014).

or international government agencies. The introduction of the United States National Ocean Policy is one example of a policy change specifically intended to facilitate this type of collaboration. Executive Order No. 13547, which established the United States National Ocean Policy, was designed to "[ensure] a comprehensive and collaborative framework for the stewardship of the ocean, our coasts, and the Great Lakes that facilitates cohesive actions across the Federal Government, as well as participation of State, tribal, and local authorities, regional governance structures, nongovernmental organizations [NGOs], the public, and the private sector."[105]

Because many sources of data are held outside the government sector, collaboration and cooperation with NGOs and the private sector also may be critical. For example, BirdLife International maintains tracking data from more than 80 researchers.[106] These data can assist regional fisheries management organizations, to, for example, reduce seabird bycatch in tuna fisheries. Coordination may be less of a challenge with open-access data sources, but in some cases high levels of institutional collaboration may be required. For example, some NGOs have also been working on compiling fisheries data across spatial scales, and these data are also available through domestic and international organizations such as NOAA and the UN Food and Agriculture Organization.[107] These data are not currently compiled on time frames that would be useful to DOM, but combining global, regional, and national datasets might provide useful data that could contribute to DOM in the future. Such resource use data may also be used in models along with real-time data.[108]

4. *Use of new data collection technologies*

New technologies exist that are cost effective for collecting both human use and biological data. While data collection via

105. Exec. Order No. 13547, 75 Fed. Reg. 43021, 43024 (Jul. 19, 2010).

106. *See* BIRDLIFE INT'L, *supra* note 79.

107. *See, e.g.*, *Marine Mammal and Turtle Science: Protected resources Databases*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. OFF. SCI & TECH., http://www.st.nmfs.noaa.gov/marine-mammals-turtles/database/index (last visited Mar. 31, 2014) (providing links to open-access databases providing real-time tracking of protected marine species, including the Protected Species Incidental Take database and the Protected Resources-Species Information System database).

108. *See Frequently Asked Questions – Sea Around Us Project Catch Mapping*, SEA AROUND US PROJECT, http://www.seaaroundus.org/faq.htm (last visited Feb. 22, 2014).

electronic tags and satellites is well established,[109] the legal issues surrounding the use of new technologies that allow *in situ* collection of oceanographic data are less clear. For example, autonomous marine vehicles (AMVs) are potentially an important future source of data for DOM. However, the use of AMVs in dynamic marine management has been hampered by perceived uncertainty over their legal status. In the United States, for instance, no liability regime exists specifically for AMVs to cover collisions with other vessels. American scholars have suggested that AMVs are likely considered "vessels," which require their compliance with various provisions of the International Regulations for Preventing Collisions at Sea (COLREGS).[110] Similar discussions are underway at the European Defense Agency.[111] At the time of writing there have been no American cases defining a vessel to include AMVs, although some commentators argue that they would fall within the definitions for purposes of the Law of the Sea.[112] If AMVs are determined to be "vessels," a host of laws and regulations could apply to their use, which could diminish some of the economic benefits arising from their use, particularly with regard to enforcement and data collection for DOM. If AMVs cannot be used with logistical and economic ease and efficiency, they may not be able to operate on the short time scales necessary for DOM.

5. *Animal ethics*

Animal tracking creates legal concerns regarding animal ethics. As a result of the long-standing debate and uncertainty surrounding the ethics of tagging marine mammals in particular, some jurisdictions rely on national marine mammal and protected species regulations, codes of practice for using animals in research, or evaluations by ethics committees to control animal tagging.[113] In

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109. *See supra* Table 1.

110. *See* Michael R. Benjamin & Joseph A. Curcio, *Colregs-Based Navigation of Autonomous Marine Vehicles*, 2004 PROC. SYMPOSIUM ON AUTONOMOUS UNDERWATER VEHICLE TECH. 32, 35 (2004) (suggesting that AMVs will likely be responsible for observing COLREGS).

111. *See Call for Papers: Safety & Regulations for European Unmanned Maritime Systems*, EUR. DEF. AGENCY (Jan. 10, 2014), http://www.eda.europa.eu/info-hub/news/2014/01/10/call-for-papers-safety-regulations-for-european-unmanned-maritime-systems.

112. Rob McLaughlin, *Unmanned Naval Vehicles at Sea: USVs, UUVs, and the Adequacy of the Law*, 6 J.L. INFO. & SCI. 2, 4 (2012).

113. See *Southern Resident Killer Whale Tagging: Frequently Asked Questions*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES,

most countries, tagging projects must undergo an animal ethics review.[114] These reviews typically result in approvals being granted only if the management and population-level benefits of appropriately conducted animal tracking outweigh the cost to the animals.[115] In the United States, for example, NOAA supports satellite tagging of whales because the resulting data are more cost effective, detailed, and accurate than that from aerial surveys.[116] Guidelines on the appropriate weight of tags (for example, <5% of body mass), and use of anesthetic during tag attachment are also common for a range of other species, with penalties for institutions or individuals who breach these guidelines.[117]

E. *Element 5: Decision-making Processes*

For voluntary DOM, individuals undertaking an activity like fishing or vessel navigation make independent decisions following receipt of information from a research or management institution. For example, the voluntary TurtleWatch program specifies the location of isotherms[118] that encompass most turtle activity and bycatch in the North Pacific.[119] However, this guidance is not ratified, regulated, or enforced by the management agency. For compulsory DOM systems, a more formal decision-making process is required.

1. *Scientific and technological issues*

The appropriate management agency, research institution, or NGO generally decides the rules by which the DOM will operate.

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http://www.nwfsc.noaa.gov/research/divisions/cb/ecosystem/marinemammal/satellite_tagging/faq.cfm. (last visited Mar. 30, 2014); *see also* SOC'Y FOR MARINE MAMMALOGY, GUIDELINES FOR THE TREATMENT OF MARINE MAMMALS IN FIELD RESEARCH 8, *available at* http://www.marinemammalscience.org/images/stories/file/Ethics/Ethics%20Guidelines.pdf (last visited Mar. 30, 2014) (noting the potential short-term impacts of tagging).

114. Selina Bryan, *Tagging Marine Animals: Valuable or Violation?*, ABC ENV'T, Apr. 11, 2011, *available at* http://www.abc.net.au/environment/articles/2011/04/11/3186168.htm.

115. *See, e.g.*, Clive R. McMahon et al., *Applying the Heat to Research Techniques for Species Conservation*, 21 CONSERVATION BIOLOGY 271, 271 (2006).

116. *See* NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, *supra* note 113.

117. *See, e.g.*, MARKUS HORNING, APPLICATION FOR A PERMIT FOR SCIENTIFIC RESEARCH TO ENHANCE THE SURVIVAL OR RECOVERY OF A STOCK UNDER THE MARINE MAMMAL PROTECTION ACT AND THE ENDANGERED SPECIES ACT, 8, 19-20 (2006), *available at* http://www.nmfs.noaa.gov/pr/pdfs/permits/horning_ssl_1034-1887.pdf (explaining why proposed research complies with NOAA's standards for tag weight as percent of body mass and use of anesthesia in Stellar's sea lion research).

118. Isotherms define regions of temperature, for example, the 25°C isotherm.

119. *See* Howell *et al.*, *supra* note 2, at 271.

In the case of regulated activity, the data product generated may not be the final product that is useful for management agencies. For example, in Australia, raw habitat preference maps for bluefin tuna are divided into three management zones, based on probability of occurrence of tuna habitat.[120] These zone decisions were initially reached by consultation between scientists and the management agency and required running many simulations so managers could see potential results of different trade-offs.[121]

Evaluating trade-offs among resource users and between conservation goals will be an important component of effective DOM applications. Online products such as MarineMap[122] and SeaSketch[123] are web-based tools that allow users to explore spatial data layers and to compare a suite of user-proposed solutions by referencing pre-defined science- and management-based goals.[124] For example, the merits of a proposed dynamic protected area could be assessed based on the level of lost fishing activity, how much farther a fisher must travel and their related fuel costs, and the conservation benefits for protected species and key habitats. Integration of multiple objectives maximizes a suite of goals for the particular spatial management approach. While tools such as MarineMap and SeaSketch have not yet been applied in a dynamic context, real-time dynamic applications of these tools are technically feasible.

Management agencies may use other spatial information as part of the DOM decision-making process. The location of Ecologically or Biologically Significant Areas, Important Bird Areas, or Key Biodiversity Areas may inform decision-making and change management action inside these regions.[125] BirdLife's Marine e-Atlas provides details of the location, boundaries, and qualifying species present at over 3000 priority sites for seabird conservation.[126] It also links to case studies on threats and management actions underway for species and sites.[127]

While the decision-making phase is usually not part of the

120. *See* Hobday & Hartmann, *supra* note 5, at 373.

121. *See* Hobday et al., *Tagging*, *supra* note 8, at 395-401.

122. MARINE MAP, marinemap.org (last visited Mar. 31, 2014).

123. SEA SKETCH, www.seasketch.org (last visited Mar. 31, 2014).

124. THE NATURE CONSERVANCY, *supra* note 48.

125. *See Using IBAs in Planning the Protection of Oceans*, BIRDLIFE INT'L, http://www.birdlife.org/datazone/sowb/casestudy/551 (last visited Mar. 31, 2014).

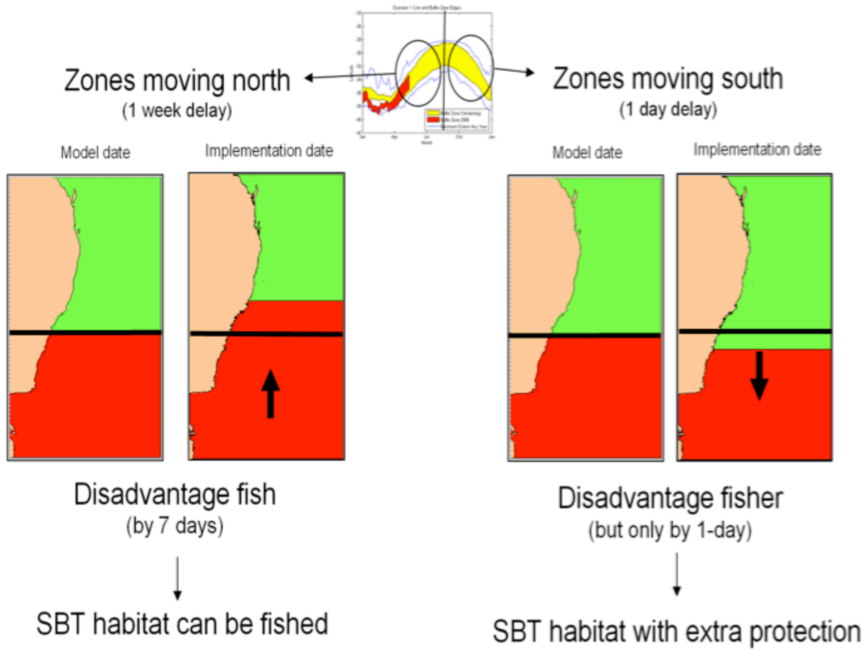
126. *Sites – Important Bird Areas*, BIRDLIFE INT'L, http://www.birdlife.org/datazone/site (last visited Mar. 31, 2014).

127. *See Marine e-Atlas*, BIRDLIFE INT'L, http://maps.birdlife.org/marineIBAs/default.html (last visited Mar. 31, 2014).

scientific contribution to DOM, scientists should be prepared to engage with this process and provide a range of alternatives. This allows the management agency to take account of other social and economic issues. In the case of southern bluefin tuna, scientists have undertaken a range of analyses that illustrate the consequences of particular decisions and have been used to refine the DOM approach (for example, delays in implementation).[128] Decision rules may also change over time, and the DOM approach may be modified. With replicable, accurate processes behind the generation of things like habitat forecasts, managers can develop these new decision rules as part of the application of DOM.

128. *See* Hobday et al., *Season Forecasting*, *supra* note 2, at 909; *see also infra* Figure 2.

Figure 2: Dynamic Ocean Management for Southern Bluefin Tuna (SBT) on the East Coast of Australia.



* As zones excluding fishers moved north, vessels were initially given seven days to exit the region, which disadvantaged SBT. When zones moved south, fishers could move into the new area (not expected to have SBT) within one day, which disadvantaged the fishers by only one day. When scientists discussed this issue with the management agency, managers subsequently implemented a two day delay for all movements of the zones.

2. *Legal issues*

The legal issues arising in the decision-making element depend to some extent on whether the DOM approach is part of a formal regulatory arrangement or a voluntary initiative such as the TurtleWatch program. For regulatory models, a successful management decision requires the most appropriate and responsive governance arrangements. In addition to governance structure, the policies and regulations that management supports must also be framed in a way that facilitates DOM. Where legal restrictions impact DOM, the DOM decision-making agency must work within its statutory authority to regulate fisheries or other marine resources. These decisions may be judicially reviewable and challenged if they exceed the agency's statutory mandate or if the prescribed decision-making process is not followed. By definition, DOM is responsive to real-time changes in social (for example fishing vessel movements) and environmental factors. It therefore requires high levels of adaptability. Yet legal regimes typically favor processes resulting in decisions that grant resource users certainty.[129] Statutes that specify detailed processes, such as stakeholder consultation by which marine protected areas and other restrictions are determined, may therefore significantly impede the wider use of DOM, since it is unlikely these processes can be followed within the short timeframes that DOM demands.

DOM decisions based only on administrative guidelines and policies may not withstand judicial scrutiny, in the same way that courts in the United States have struck down agency decisions based on administrative policies of adaptive management.[130] Yet courts have carefully explained that dynamic management is not problematic per se; rather it is only the application at hand that is problematic.[131] Where statutory procedures prove to be impediments to wider uptake of DOM, it may be necessary to amend these laws. Frameworks will be needed that are based on outcomes-focused criteria that permit regulatory changes in near real time on a regular basis, rather than seasonal closures or

129. Michael P. Van Alstine, *The Costs of Legal Change*, 49 UCLA L. REV. 789, 813 (2002) (explaining that the preference for certainty arises from benefits like reduced transaction costs and efficient decisionmaking). However, the rate of legal change is increasing rapidly, in part because of the proliferation of extra-legislative bodies at the national and international levels, which have the power to create law both formally and informally. *Id.* at 792.

130. *Cf., e.g.*, Natural Res. Def. Council v. Kempthorne, 506 F. Supp. 2d 322, 356-57 (E.D. Cal. 2007) (rejecting an adaptive management plan as too uncertain for the purposes of mitigation under the Endangered Species Act); Carl Folke et al., *Adaptive Governance of Social-Ecological Systems*, 30 ANNUAL REV. ENVTL RES. 441, 449 (2005) (explaining that adaptive governance of ecosystems often balances decentralized and centralized control, which is spread among quasi-autonomous decisionmaking units); J.B. Ruhl & Robert L. Fischman, *Adaptive Management in the Courts*, 95 MINN. L. REV. 424, 445 (2010) (noting that at least thirty-one federal court decisions have considered adaptive management, of which the United States has lost more than half). The Ninth Circuit recently fractured on adaptive management-related issues, entering four separate opinions in a NEPA case; the dissent explained that deference regarding the amount of monitoring necessary was required because it is an area that demands a high level of technical expertise. Sierra Forest Legacy v. Sherman, 646 F.3d 1161, 1202 (9th Cir. 2011) (per curiam).

131. Ruhl & Fischman, *supra* note 130, at 447. For example, in *Kempthorne*, while the court carefully noted that all parties agreed to the benefits of adaptive management, it nonetheless rejected the adaptive management practice at issue because it was not reasonably certain that appropriate mitigation would be implemented, as required by the Endangered Species Act. 506 F. Supp. 2d 322, 356 (E.D. Cal. 2007).

emergency closures due to bycatch.

Similar problems may arise where permits and other statutory fishing rights purport to confer absolute property rights that cannot be modified or constrained. Takings claims for compensation may arise where an agency revokes or limits fishing rights pursuant to DOM decision-making.[132] At present, some regimes allow for emergency closures mid-season or for closure following the maximum take of a protected species.[133] If DOM is to become the "new normal" model of marine resource decision-making, however, invocation of these exceptional powers will be insufficient. It will be necessary for permit conditions to clarify that changes may be made at any time and multiple times throughout a season, as occurs in management of the Eastern Australian Longline Fishery.[134]

Other potential issues might arise if the information upon which a DOM decision is made proves to be inaccurate. Generally, courts only overturn administrative decisions where they are manifestly unreasonable, or arbitrary or capricious.[135] Agencies receive even greater deference when relying on scientific expertise.[136] If the data underpinning a DOM decision prove to be incorrect, it may provide grounds to overturn the closure or other restriction, but would probably not entitle the fisher to claim compensation from the management agency for any losses incurred as a result of the closure.

Fishers could potentially challenge those organizations that collect and process the data upon which decisions are made, although it may be virtually impossible for an individual fisher to prove that a closure or other restriction was based on incorrect data and that this closure caused them economic loss. Appropriate

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132. It is unclear how this would play out in an international regulatory context. *See, e.g.*, Vicki Been, *The Global Fifth Amendment: NAFTA's Investment Protections and the Misguided Quest for an International Regulatory Takings Doctrine*, 78 NYU L. Rev. 30, 141-42 (2003) (arguing that an expansive takings doctrine would be inappropriate in the international regulatory context).

133. *See, e.g.*, Grantham et al., *Closures*, *supra* note 3, at 291.

134. *See* Hobday et al., *Seasonal Forecasting*, *supra* note 2, at 899.

135. 5 U.S.C. § 706(2)(a) (2012); *accord* Chevron U.S.A., Inc. v. Natural Res. Def. Council, 467 U.S. 837, 844 (1984).

136. *See* Oceana, Inc. v. Evans, 384 F. Supp. 2d 203, 212 (D.D.C. 2005) ("It is especially appropriate for the District Court to defer to the expertise and experience of those individuals and entities whom the Magnuson-Stevens Act charges with making difficult policy judgments and choosing appropriate conservation and management measures based on their evaluations of the relevant quantitative and qualitative factors.") (quoting Nat'l Fisheries Inst. v. Mosbacher, 732 F.Supp. 210, 223 (D.D.C.1990)).

disclaimers can minimize this risk of liability. Disclaimers should state that the user accepts that the information is only a best available estimate and that the supplier gives no express or implied warranty as to its accuracy. If the information is provided on a website, the user should have to accept the terms and conditions before gaining access to the site. Alternatively, if the information is made available on a subscription basis, the written contract should also provide that it is provided without any express or implied warranty.

F. *Element 6: Implementation*

1. *Scientific and technological issues*

Successful implementation of a DOM approach will require a suite of tools. For example, users from one sector (for example, shipping) may require geo-referenced information on existing closures or coincident activities by users from other sectors (for example, oil and gas). Some sectors may require information on changes in market conditions as stand-alone output or as a linked function of oceanographic conditions or management closures. These tools will need the flexibility to display results in familiar unit conventions (for example, degrees Celsius versus Fahrenheit or Universal Transverse Mercator versus latitude/longitude). Web services supporting innovative uses of mobile devices and near-real-time map generation and distribution will be needed to augment continued delivery of information via radio, phone, fax, and email.

In recent years, several such tools have been developed to meet these needs for fisheries.[137] These applications give end users an accessible way to capture, identify, visualize, and share spatially explicit data and model output. For example, the Food and Agricultural Organization's (FAO) Fisheries Activity Simulation Tool allows comparison of different fishing strategies based on different spatial restrictions.[138] Given that end users of DOM also play a central role in collecting and utilizing data underpinning the approaches, these tools represent an important step in engaging these end users, developing DOM tools, and encouraging compliance for fisheries and other sectors such as shipping. Additionally, commercial services like Roffer's Ocean

137. *See, e.g.*, THE NATURE CONSERVANCY, *supra* note 48.

138. *See Fisheries Activity Simulation Tool*, UNITED NATIONS FOOD & AG. ORG., FISHERIES & AQUACULTURE DEP'T, http://www.fao.org/fishery/topic/4110/en (last visited Mar. 31, 2014).

Fishing Forecasting Service and Seastate provide fishers with actionable information within an operational timeframe.[139] To be successful, DOM must do likewise and match the temporal and spatial scales to operations across sectors. Future applications that can incorporate and integrate multiple data streams, sources, and types, and help user groups weigh costs and benefits of a particular activity in real time will be needed in the next generation of DOM implementation tools.

2. *Legal issues*

Compulsory DOM depends on the ability to distribute regulations and restrictions quickly and effectively to all relevant stakeholders. These changes must be widely broadcast to notify marine users who are active in the relevant region. Legal notice of changes is critical in enforcement actions. A breach may be dismissed if changed requirements are not adequately communicated. Agencies considering the implementation of DOM approaches must therefore ensure that the system for communicating changes is specified in relevant permits and authorizations. Ideally, vessels should be required to acknowledge receipt of new information. In many locations, fishing vessels must have VMS.[140] These systems use radio equipment to communicate fisheries information via satellite to onshore operators who also have access to a vessel's position, course, and speed.[141]

G. *Element 7: Enforcement and Compliance*

1. *Scientific and technological issues*

Without compliance to support DOM decisions, the expected benefits are not likely to be realized. While DOM programs may be mandatory or voluntary, voluntary measures have had limited success, particularly in the open ocean. For example, the success of the final Rule to Implement Speed Restrictions to Reduce the Threat of Ship Collisions with North Atlantic Right Whales has

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139. *See* ROFFER'S OCEAN FISHING FORECAST SERVICES, http://www.roffs.com/ (last visited Mar. 31, 2014).

140. *See* AUSTL. COMMC'N AND MEDIA AUTH., MARINE SATELLITE COMMUNICATIONS AND VESSEL MONITORING SYSTEMS 1 (2001), *available at* http://www.acma.gov.au/webwr/aca_home/publications/reports/info/vessel-monitoring-systems.pdf (noting that "[f]isheries management authorities throughout the world are progressively requiring commercial fishing operators to fit their vessels with VMS").

141. *Id.*

been limited despite the Rule's robust design.[142] Under the Rule, ships are requested to slow down in areas where there is an aggregation of North Atlantic right whales.[143] Ships receive notice of these aggregations through a variety of mechanisms, including NOAA Weather Radio broadcasts that are transmitted regularly for the full duration of the DOM area, United Coast Guard (USCG) broadcast notices to mariners, an email distribution list, a mandatory ship reporting automatic return message to vessels, postings on the NMFS Office of Protected Resources ship strike website and Northeast Fishers Science Center interactive right whale sightings "mapper," and automatic return messages sent to mariners requesting information by e-mail.[144] Despite this range of communication tools, the voluntary measures have had limited success. The recorded speed reductions have been minimal. Reviews of the program recommend mandatory measures.[145]

A range of technical options now exists to evaluate compliance with DOM requirements. Fishing vessels can be monitored with on-board observers, VMS, and by satellite.[146] Observer programs can monitor levels of seabird bycatch and track the progress of mitigation measures. VMS has become an essential component of monitoring control and surveillance programs across many regions.[147] Approved VMS equipment and operational use vary according to country requirements. Leaving aside the potentially prohibitive cost of VMS for some areas, using VMS to monitor vessel movements requires assurance that vessels will not be able to override VMS data about their boats' locations.[148] The European Union has addressed this problem by requiring technical specifications for VMS tracking devices, known as vessel detection systems, that prevent vessel operators from overriding VMS

142. Speed Restrictions to Protect North Atlantic Right Whales, 73 Fed. Reg. 60,173, 60,174 (Oct. 10, 2008) (codified at 50 C.F.R. pt. 224).

143. *Id.* at 60,174.

144. *Id.*

145. GREGORY K. SILBER & SHANNON BETTRIDGE, AN ASSESSMENT OF THE FINAL RULE TO IMPLEMENT VESSEL SPEED RESTRICTIONS TO REDUCE THE THREAT OF VESSEL COLLISIONS WITH NORTH ATLANTIC RIGHT WHALES, NAT'L OCEANIC & ATMOSPHERIC ADMIN. TECHNICAL MEMORANDUM NMFS-OPR-48 at 1 (2012).

146. *See* Molenaar & Tsamenyi, *supra* note 46, at 80.

147. *See id.* at 32-40 (describing the use of VMS in monitoring programs in several countries).

148. Kristina M. Gjerde et al., *Ocean in Peril: Reforming the Management of Global Ocean Living Resources in Areas Beyond National* Jurisdiction, 74 MARINE POLLUTION BULL. 540, 544 (2013) (noting that "[i]t is often easy to . . . disable vessel monitoring systems").

systems.[149] In the United States, the cost of VMS systems may provoke legal challenges. Under the MSA, for example, conservation measures must minimize costs and adverse economic impacts on fishing communities.[150] In *Blue Water Fisherman's Association v. Mineta*, the D.C. District Court found that regulations requiring VMS on all United States pelagic longline vessels with permits to fish for highly migratory Atlantic species violated the MSA because the regulation was not narrowly tailored.[151] The VMS requirement at issue was not limited to those vessels that would encounter closed or restricted areas. Because DOM would require a large number of vessels to install VMS or similar systems, as in *Mineta*, it is thus unclear whether such a requirement would be consistent with the MSA.

Where DOM programs operate on a voluntary basis, there are no real enforcement strategies available in cases of non-compliance. Where compliance with DOM decisions is mandatory—by virtue of regulations or permit conditions—enforcement still requires real-time access to high-quality compliance data.

2. *Legal issues*

Successful enforcement proceedings against ocean users who breach DOM decisions will require clear, unambiguous legal requirements. There must be evidence that regulations have been communicated to affected users and evidence that users breached the regulations. Finally, the violating vessels must be apprehended or sanctioned. The development of Unmanned Maritime Systems (UMS) including both waterborne AMVs and aerial unmanned systems promises to provide greater compliance and enforcement opportunities. The USCG is experimenting with unmanned surface vehicles such as wave gliders, coupled with unmanned aerial systems, to gather and relay data regarding illegal fishing to appropriate enforcement agencies.[152] Enforcement officials can use this data to detain vessels at the dock rather than attempting to intercept the vessels at sea.

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149. *See* INST. FOR THE PROTECTION AND SEC. OF THE CITIZEN, FISHREG: SCIENTIFIC & TECHNICAL SUPPORT OF THE COMMON FISHERIES POLICY, THE VESSEL DETECTION SYSTEM 1 (2007), *available at* http://ec.europa.eu/research/press/2007/maritime-briefing/pdf/43-vessel-detection-system-fisheries_en.pdf.

150. 16 U.S.C. § 1851(a)(8) (2012).

151. 122 F. Supp. 2d 150, 169 (D.D.C. 2000).

152. *See* Vasilios Tasikas, *Unmanned Aerial Vehicles and the Doctrine of Hot Pursuit: A New Era of Coast Guard Maritime Law Enforcement Operations*, 29 TUL. MAR. L.J. 59, 66 (2004).

While promising in theory, this approach must overcome legal obstacles. In particular, data must be authenticated and validated to ensure that it is admissible in legal proceedings. To ensure that remote monitoring data is admissible, the submitting agency must be able to establish the violation's exact location, date, and time, the data's reliability, and the data chain of custody's integrity. Undoubtedly, there will be test cases in which the admissibility of remotely gathered data is ascertained, just as test cases were brought to challenge the use of radar to control speeding motor vehicles.[153]

Which national or sub-national government has jurisdiction will depend on the location of the infraction and on legal instruments through which DOM decisions are implemented. There may be some circumstances in which there is overlap between the jurisdictional reach of national and state or provincial government fisheries laws. For enforcement beyond a sub-national government's territorial waters (typically three nautical miles), the national government will have exclusive jurisdiction.[154] Within the three-mile zone, either the state or federal governments may be entitled to bring enforcement proceedings, depending on the legal instruments by which DOM decisions are implemented.

DOM programs that operate on the high seas and across the national waters of multiple countries will face the same enforcement challenges that plague international maritime law more generally. Enforcement mechanisms under international conventions may offer some guidance. For example, enforcement of the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean falls principally to the flag state of a vessel that is in violation.[155] The Convention incorporates a regional-observer program charged with data collection and monitoring implementation. The program also uses satellite imagery to track

153. *See, e.g.*, Yolman v. State, 388 So.2d 1038, 1039-40 (Fla. 1980) (affirming the use of doppler radar to determine speed accuracy).

154. *See* United Nations Convention on the Law of the Sea (UNCLOS), art. 3 *opened for signature* Dec. 10, 1982, 1833 U.N.T.S. 397 (entered into force Nov. 16, 1994) (defining zone of exclusive jurisdiction at three nautical miles); *accord* Proclamation No. 5928, Territorial Sea of United States of America, 54 F.R. 777, 777 (Dec. 27, 1988) (proclaiming three nautical miles as American territorial sea); *Maritime Zones and Boundaries*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. (Aug. 12, 2013), http://www.gc.noaa.gov/gcil_maritime.html (defining U.S. zone of exclusive jurisdiction as three nautical miles).

155. Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean, arts. 23(2)(c)(4), 24, June 19, 2004

fishing vessels within the Convention area; information is passed simultaneously to flag states and the Convention. Vessels must use near real-time satellite position fixing transmitters when they are within certain protected areas.[156] Procedures are intended to "protect the confidentiality" of VMS information, and member states cooperate to ensure the compatibility of national and high seas VMS.[157]

III. IMPLEMENTING THE SEVEN ELEMENTS OF DYNAMIC MANAGEMENT

A. *Capacity for Dynamic Ocean Management*

Before identifying a DOM approach for a particular policy goal, it is important to consider the legal system and user-oriented capacities of that system. While the benefits of DOM may be advantageous for a broad range of issues, the ultimate success of a dynamic approach will be determined by how well it fits the specific location and management challenge.

Protected areas that move among different sovereign waters may encounter problems of coordination in the decision-making, implementation, and enforcement elements. Further adding to the challenge is that countries and businesses may view dynamic fisheries management as an economic threat: providing fisheries data could lead to limits or bans on catches.[158] Incentivizing honest and transparent participation likely will be an essential component of any successful DOM program.

In addition, language and communication barriers could create fragmented implementation, enforcement, and coordination problems. Any DOM effort that stretches beyond a single country's borders must promote training and education in relevant scientific, management, technological, and legal capacity. These efforts should promote intercultural understanding so that programs and enforcement efforts are consistent with various cultural norms and institutions. Furthermore, programs should incorporate regional negotiations so that less powerful countries have a voice. Inclusive modes of decision-making also will create a

156. Sean D. Murphy, *Conservation of Fish in the Western and Central Pacific Ocean*, 92 AM. J. INT'L L. 152, 154 (2001).

157. *Id.* (noting that "[t]he procedures adopted by the Commission shall include appropriate measures to protect the confidentiality of information received through the vessel monitoring system. Any member of the Commission may request that waters under its national jurisdiction be included within the area covered by such vessel monitoring system.").

158. *See, e.g.*, Grantham et al., *Closures*, *supra* note 3, at 291.

collaborative environment that promotes cooperation.

Challenges also exist for extending capacity and willingness to resource users. Fishers or other stakeholders may perceive DOM approaches as frequently changing regulations that are difficult to plan for and comply with. This may challenge policymakers, who might receive frequent complaints and resistance, to persist in using DOM. Thus a key element for a successful DOM program will be policymakers effectively communicating that DOM will reduce overall restrictions, for example, by reducing the amount of closed areas, and benefit by increasing profits. A related challenge will be enhancing user capacity such that all users who are subject to DOM regulations have both the technical means and appropriate education and training to abide by the rules. Equipping users with vessel and communication technologies discussed above—such as mobile phones, VMS, and other environmental gauges—will be essential so that they can receive, process, and implement DOM measures while at sea. Furthermore, users must understand the objectives and specifications of the management approach in order to respond properly and consistently to dynamic regulations. One example of this consideration is the potential presence of language barriers between managers and users. Heterogeneous systems where users are characterized by differing technical capacity, backgrounds, and training levels present challenging situations and may undermine DOM if only a select group of users is capable of implementing the management program.

These considerations represent only a few of the ways in which some systems may better lend themselves to certain types of DOM than others. Accounting for differences in governance, scale, and user background are essential for successful management, particularly of dynamic approaches. But because DOM is flexible by design, the technologies and policies of various approaches may be adapted to respond to a suite of different contexts and circumstances.

B. *Sustainability of Dynamic Ocean Management*

Requirements for DOM include management capacity to support DOM tools in terms of expertise, computer systems and software, and the ability to maintain these needs within existing and future financial constraints. Understanding the specific needs, requirements, and capabilities of management and other user groups is therefore a critical first step for effective DOM. If a regulatory agency develops a DOM program, then these needs are most likely to be met and the stages in the DOM approach well connected. However, if the models and tools are developed by other institutions,[159] then the DOM program may need to be transitioned to the management agency for operational use.[160] This will require communication between the developer and management agency to ensure that the user is prepared for the necessary computer system and/or data storage requirements and is trained on how to use, interpret, and apply the tools developed to implement a DOM program. Appropriate software licenses and data agreements may be required if the DOM tool requires particular programs or information to function.

In adapting to the changing ocean environment, DOM maximizes benefits to the ecosystem and reduces conflicts with human activities. Achieving this result requires regular information about the ocean environment. The availability and accessibility of data now and in the future should therefore be considered when determining the most appropriate inputs for creating not just an ecological model, but a sustainable, operational DOM tool. The availability of required environmental inputs may change because of changes to sensors or to funding. For example, calibrations of the derived sea surface chlorophyll concentrations were necessary when the ocean color sensor SeaWiFS (Sea-viewing Wide Field-of-view Sensor) was replaced by MODIS (Moderate Resolution Imaging Spectroradiometer).[161] There are concerns that the new replacement, VIIRS (Visible Infrared Imaging Radiometer Suite), has a lower spatial resolution than MODIS.[162] A lower spatial resolution could limit some ecosystem monitoring applications in the future.

Additionally, a number of key environmental variables are derived from data collected by sensors on satellites. Many of these products from American satellites are currently available from the National Aeronautics and Space Administration for free, but their availability is not guaranteed for the future.[163] As some satellite sensors will reach the end of their lifespan before the next ones

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159. *See* discussion *supra* Parts II(A)-(D); Figure 1.

160. *See* discussion *supra* Parts II(E)-(G).

161. *See* OCEAN PRODUCTIVITY, *supra* note 103.

162. Robert E. Murphy et al., *Using VIIRS to Provide Data Continuity with MODIS*, 3 GEOSCIENCE & REMOTE SENSING SYMP. 1212, 1212 (2001).

163. *See VIIRS Products*, NAT'L AERONAUTICS & SPACE ADMIN. SHORT-TERM PREDICTION RES. & TRANSITION CTR., http://weather.msfc.nasa.gov/sport/jpsspg/viirs.html (last visited Apr. 3, 2014).

are launched, there may be a lack of continuity in data. Some countries already charge for access to their satellite-produced data. Such costs should be considered when calculating the expense of maintaining DOM tools. Ocean models alternatively may be used as environmental inputs in habitat preference models.[164] As with all models, these may be subject to modification over time. It is therefore advisable to have a mechanism in place for incorporating updated model inputs into existing products. This is also the case for data on animal distributions. Although longer-term datasets may include species distributions during a range of natural variations, there may be changes to ocean conditions in the future. Such future conditions may include higher water temperatures as a result of climate change than previously experienced.[165] Determining the responses of marine species and humans to such conditions will require other data sources or new data collection to validate, and if necessary, modify the products so that they continue to provide accurate outputs for DOM.

IV. CONCLUSION

Given all the scientific, legal, and political challenges outlined above, it is reasonable to question whether a full exploration of the science and policy potential of DOM is worthwhile and sensible. While it may require a major shift in how we manage marine resources in some areas and sectors, it is necessary to increase the sustainability of ecological and economic benefits derived from marine systems. We caution, however, that DOM may not be appropriate for all species, particularly in coastal areas where species are sessile and slow growing, or living on the ocean floor. In such cases, DOM may inadvertently expose species needing long-term protection.[166]

TurtleWatch and dynamic management areas to reduce whale strikes provide the opportunity for ocean users to reduce their

164. *Id.*

165. *See* Alistair J. Hobday et al., *Climate Impacts and Oceanic Top Predators: Moving from Impacts to Adaptation in Oceanic Systems*, 23 REVS. FISH BIOLOGY & FISHERIES, 537, 538 (2013) (referencing global warming as an impact on oceanic ecosystems being investigated).

166. *See* Laura Rogers-Bennett et al., *Dramatic Declines in Red Abalone Populations after Opening a* ''De Facto'' *Marine Reserve to Fishing: Testing Temporal Reserves*, 157 BIOLOGICAL CONSERVATION, 423, 431 (2013) (concluding that adopting potentially short-term marine reserves which are periodically opened for fishing for long-lived species, like abalone and tuna, may be insufficient to protect the species).

impact on protected species on a voluntary basis.[167] Whether these systems should, under some conditions, be mandatory is a regulatory decision. This article provides examples of challenges and opportunities for making DOM compulsory. It also considers one of the few examples where DOM is mandated, the Eastern Australian longline fishery.[168] While we explore the existing technologies available for DOM, future technologies could make DOM increasingly attractive and inexpensive. Costs will likely decrease as satellite-based communications become more accessible to ocean users. For example, the costs of satellite-based communication devices may decrease over time. Costs will be further decreased as new data gathering and enforcement technologies are developed, such as less-expensive and longer-range alternatives to AMVs and gliders. Furthermore, if the ocean users themselves became more engaged in reporting species interactions or remotely recording species' spatial behavior, this information could be incorporated in updating projected conflicts.[169]

DOM, as described here, is a relatively expensive approach to marine management, particularly in the early stages as data are collected and data handling systems implemented. Beyond the technical and legal issues described here, successful and enduring DOM approaches will require genuine long-term commitment by regulators. To that end, demonstration of the biological, social, and economic benefits of DOM will be critical to wider application and uptake. In order for DOM to be effective and worthwhile to all stakeholders, it must adequately protect both species of concern and opportunities for humans to use marine systems. The benefits exchange should explore whether we can protect fishing and shipping opportunities while also protecting species of concern from collateral damage. While adequate resources must be dedicated to developing DOM approaches, systems can be designed with long-term sustainability in mind, thereby causing costs associated with management to decline with time. There is significant scientific potential for more precise, dynamic

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167. *See* Howell et al., *supra* note 2, at 276 (noting that TurtleWatch is a voluntary program); Van Parijs et al., *supra* note 59, at 22 (describing potential applications of passive acoustic monitoring for tracking cetaceans and omitting any description of the technology being deployed as a regulatory requirement).

168. *See* Hobday et al., *Seasonal Forecasting*, *supra* note 2, at 898.

169. For example, a variation on traffic accident reporting applications available for mobile devices, such as Waze, could be developed for ocean users to report species interactions. *See* WAZE, https://www.waze.com/livemap (last visited Mar. 30, 2014).

approaches to managing ocean systems in a way that protects the interests of ocean users as well as effectively managing sensitive mobile marine species.