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Dynamic ocean management: Defining and conceptualizing real-time management of the ocean

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ABSTRACT

Most spatial marine management techniques (e.g., marine protected areas) draw stationary boundaries around often mobile marine features, animals, or resource users. While these approaches can work for relatively stationary marine resources, to be most effective marine management must be as fluid in space and time as the resources and users we aim to manage. Instead, a shift towards dynamic ocean management is suggested, defined as management that rapidly changes in space and time in response to changes in the ocean and its users through the integration of near real-time biological, oceanographic, social and/or economic data. Dynamic management can refine the temporal and spatial scale of managed areas, thereby better balancing ecological and economic objectives. Temperature dependent habitat of a hypothetical mobile marine species was simulated to show the efficiency of dynamic management, finding that 82.0 to 34.2 percent less area needed to be managed using a dynamic approach. Dynamic management further complements existing management by increasing the speed at which decisions are implemented using predefined protocols. With advances in data collection and sharing, particularly in remote sensing, animal tracking, and mobile technology, managers are poised to apply dynamic management across numerous marine sectors. Existing examples demonstrate that dynamic management can successfully allow managers to respond rapidly to changes on-the-water, however to implement dynamic ocean management widely, several gaps must be filled. These include enhancing legal instruments, incorporating ecological and socioeconomic considerations simultaneously, developing 'out-of-the-box' platforms to serve dynamic management data to users, and developing applications broadly across additional marine resource sectors.

1. Introduction

Marine resource management has historically paralleled management in terrestrial systems [1]. Marine protected areas, marine spatial planning, and quota-based systems (e.g., individual transferable quotas, bag limits) are all based on terrestrial management [2–7], but the open oceans differ from terrestrial systems in several important ways. In terrestrial and nearshore marine systems,

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stationary or long-lived primary producers often create or aid in the creation of habitat structure (e.g., terrestrial forests, grasslands; kelp forests, seagrass beds, coral reefs) [5,8]. In contrast, marine autotrophs in pelagic systems are primarily microscopic and short-lived, and three-dimensional habitat structure is instead created by oceanographic features where primary producers are retained, forming the foundation for food webs that attract larger consumers [9,10]. Additionally, compared with terrestrial ecosystems, the oceans are in constant flux, affecting the species and resource users which are being managed. Physical forcing of the oceanographic seascape spans multiple spatial and temporal scales [9], and dynamic biogeographic provinces are delineated by these oceanographic variables [11]. Oceanographic features that both animals and resource users follow, like fronts and eddies, move dynamically across similar scales [9,12,13]. While fisheries often focus on coarse-scale features such as the upwelling domain of eastern boundary currents [14], fisheries catch rates often vary at spatio-temporal scales matching fine-scale oceanographic features [15,16]. Similarly, animal migrations and foraging or breeding aggregations track dynamic oceanographic features across multiple scales [17–21], making habitat more difficult to define than in terrestrial systems.

Because the scale of temporal and spatial variability in the oceans is unmatched in terrestrial systems, terrestrially-derived management approaches may be too static for dynamic marine systems [2,9,10,22]. The ocean itself and the majority of ocean uses (e.g., shipping, fishing) are highly dynamic, but the majority of marine management approaches (e.g., marine protected areas, marine spatial planning, total allowable catches and quota setting) are relatively static [2,23–26]. To meet the challenge of managing this highly dynamic system, management must become as fluid in space and time as both the marine environment and the marine resource users [2,27].

2. Dynamic ocean management

Mismatches in the rate and scale at which either the marine environment changes or marine resource users act, and, in some cases, the speed with which marine resource management responds, may result in decreased efficiency and effectiveness. Toward this end, it is suggested that managers make a shift towards ***dynamic ocean management***, defined as '*management that changes rapidly in space and time in response to the shifting nature of the ocean and its users based on the integration of new biological, oceanographic, social and/or economic data in near real-time*' (Fig. 1).

Application of dynamic management requires a shift from static management measures to near real-time management. In dynamic management approaches, we can integrate: (1) existing datasets, such as remote sensing, animal tracking or fisheries observer data, (2) advanced analytical processing and modeling techniques that allow us to predict key species distributions, user behavior or oceanographic habitats in space and time, and (3) rapid data-sharing technology such as handheld devices to implement dynamic tools that respond at finer scales than have been implemented in the past. This kind of approach has only become practical in recent decades due to improvements in related technology, and due to long-term datasets on which models can be based, and datasets that will be reliably collected into the future, such via remote sensing. While dynamic management does not necessarily require a full suite of advanced technology, the capacity exists to integrate multiple data types and technology platforms. Remote sensing data are readily and often freely available [28]. Advances in animal tracking data have allowed a greater understanding of animal movement and habitats in near real-time [17,29]. Analytical processing has advanced to allow us to predict animal habitats using animal distribution data and habitat modeling techniques that incorporate near real-time remote sensing data [30–32]. Further, these models can integrate numerous data sources such as animal tracking, at-sea surveys, industry observer or user-collected data. Equally critical, data sharing technologies exist to support dynamic management [33]. Low-technology communication via radio or email is readily available and more complex communication systems through mobile technology (e.g., smartphones and tablets), and corresponding satellite and cellular data capabilities, are rapidly improving and declining in cost [34,35]. These technologies are more than adequate to engage ocean users in the two-way data sharing required by dynamic management approaches.

2.1. Dynamic management in practice

Dynamic ocean management is perhaps best illustrated by existing examples. In practice, dynamic ocean management has been applied across several sectors using both voluntary and compulsory measures [36,37]. The complexity of data driving dynamic management may vary – from simple compilation of user-generated data, to complex habitat modeling approaches – and all incorporate new data on time scales from days to months (Fig. 2). Fishermen in the New England scallop fishery voluntarily report bycatch of yellowtail flounder (*Limanda ferruginea*) on a daily basis to the School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth. SMAST then compiles the bycatch data by fishing block and distributes it by email the following day to scallop fishermen, instructing them which areas to avoid (Fig. 2a). Since the program started in 2010, fishermen have been able to fish the entire duration of the scallop season, resulting in economic gains upwards of $10 million/year over previous years [38]. In the East Australian multi-species longline fishery, managers regulate fishing effort and allocate observer coverage for quota-managed southern bluefin tuna (*Thunnus maccoyii*) [39,40] using real-time habitat predictions based on tuna's temperature-dependent habitat preferences (Fig. 2b). Using expected habitat preferences of the fish and seasonal forecasts of environmental conditions, scientists have developed models that predict where tuna are likely to occur in coming months, and as a result fishermen have avoided long-term costs associated with going over quota limits [30]. Similarly, TurtleWatch is a program developed by the NOAA Pacific Islands Fisheries Science Center designed to reduce bycatch of loggerhead sea turtles (*Caretta caretta*) in the shallow-set longline fishery based in Hawaii (Fig. 2c) [41]. NOAA scientists determined the temperature preferences of loggerhead turtles using satellite tracking and highlight areas longline fishermen should avoid to reduce sea turtle bycatch. This information is posted online every several days, based on the movements of temperature fronts in the Central North Pacific. In a non-fishery application, passive acoustic buoys and aerial surveys are used to detect the real-time presence of North Atlantic right whales (*Eubalaena glacialis*) along the US East Coast to reduce lethal ship strikes of this critically endangered species (Fig. 2d) [42]. Dynamic management area locations are distributed to ship captains via mobile applications to alert them to the whales' presence and to recommend avoiding areas or reducing speeds when whales are present [43–45]. Dynamic management areas are also paired with traditional seasonal closures of the whales' breeding grounds [42]. The ability to use near-real time management responses goes beyond animal distribution information; applications exist that integrate resource user distribution as well, including tools that leverage mobile technology. eCatch, a program designed by The Nature Conservancy, uses smartphones and tablets to rapidly share data on the location and amount of bycatch species, and has allowed the central California groundfish fishery to remain below fishery-wide quotas [46]. While these and