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MARINE GOVERNANCE

Ending hide and seek at sea

New technologies could revolutionize ocean observation

By **Douglas J. McCauley,**[1]* **Paul Woods,**[2] **Brian Sullivan,**[3] **Bjorn Bergman,**[2] **Caroline Jablonicky,**[1] **Aaron Roan,**[3] **Michael Hirshfield,**[4] **Kristina Boerder,**[5] **Boris Worm**[5]

The ocean remains the least observed part of our planet. This deficiency was made obvious by two recent developments in ocean governance: the emerging global movement to create massive marine protected areas (MPAs) (*1*) and a new commitment by the United Nations (UN) to develop a legally binding treaty to better manage high-seas biodiversity (*2*). Both policy goals cause us to confront whether it is meaningful to legislate change in ocean areas that we have little capacity to observe transparently. Correspondingly, there has been a surge in interest in the potential of publicly accessible data from automatic ship identification systems (AIS) to fill gaps in ocean observation. We demonstrate how AIS data can be used to empower and propel forward a new era of spatially ambitious marine governance and research. The value of AIS, however, is inextricably linked to the strength of policies by which it is backed.

POLICY

AIS was conceived as a navigational safety aid to prevent ship collisions. AIS transponders publicly broadcast information about a ship's identity, position, and course. The recently gained capacity for mass detection of AIS messages by satellite (S-AIS) makes it possible to observe vessel activity anywhere in the world. In coastal regions, AIS data can be viewed near real time for free, and historical AIS data can be publicly purchased from data vendors. Nonprofit organizations are working on making select AIS data products available for free, and global funders are providing developing nations with access to AIS data (*3*).

The open technologies used by AIS, and its global use, distinguish it from other regionally administered "closed-access" systems [e.g., vessel monitoring systems (VMS)] that do not pool data across jurisdictional regions, transmit data at lower rates, and tightly restrict data access. AIS, however, is not without shortcomings: It is not instantaneous (delays range from minutes to 1 hour), satellite coverage dictates data density, and it doesn't transmit data on the operation of fishing gear [see table S1 for a full comparison of observation systems (*4*)]. Hence, AIS is best viewed as a transparent, global complement to existing closed-access systems. Since 2004, the United Nations' International Maritime Organization (IMO) AIS requirements have fostered compliance for the largest

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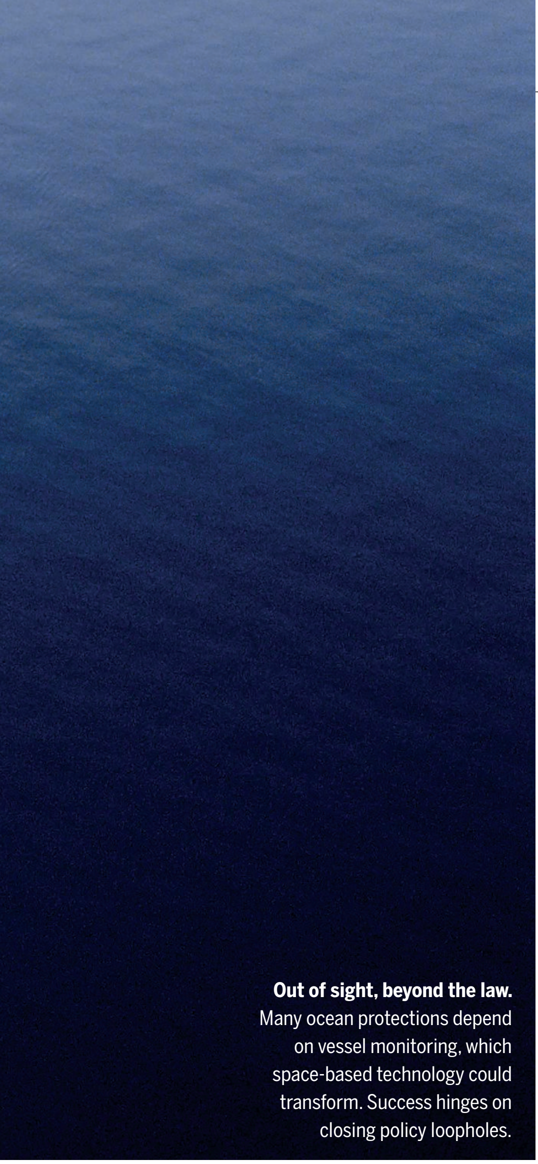

Out of sight, beyond the law. Many ocean protections depend on vessel monitoring, which space-based technology could transform. Success hinges on closing policy loopholes.

ocean-going vessels and passenger liners, but numerous vessels, notably many fishing vessels, slip through the cracks in existing IMO policy (*5*).

PROTECTED AREAS, HIGH SEAS, AND MORE. Nineteen "mega-MPAs" (>100,000 km^2) have been created or announced in the past 6 years, collectively amounting to more area than all MPAs previously gazetted. If we are to move from the ~3% of the ocean currently delineated to the 10% target for 2020 set by the Convention on Biological Diversity (*6–8*), megapark establishment will continue.

AIS provides the first tenable option for publicly accessible observation of mega-MPAs. We examined S-AIS activity data of known fishing vessels present within Kiribati's Phoenix Island Protected Area (PIPA), a California-sized MPA (i.e., ~410,000 km^2) that was closed to all commercial fishing on 1 Jan 2015 (*4*). Our data showed substantial fishing activity before closure, and a sharp drop at closure (Fig. 1). Six months of postclosure monitoring revealed only one case of fishing activity in PIPA, and this vessel was interdicted and fined by Kiribati. About 97% of vessels observed fishing in PIPA preclosure consistently used AIS postclosure, allowing additional insight into how fishermen responded to MPA closure (*4*).

S-AIS estimates of fishing effort in the PIPA region derived using algorithms that separate fishing from nonfishing behaviors (e.g., transiting) were positively correlated with effort reported from fisheries observers, [$P < 0.0001$ (*4*)] AIS, however, underestimates observer-derived effort, the latter presumably a more complete, but more resource-intensive, measure mirroring results from Atlantic land-based AIS (*9*).

About 64% of the ocean lies outside of national jurisdiction. These waters harbor unique aspects of marine biodiversity, including highly endangered species (*6*, *10*, *11*). Concern about ineffective high-seas management has been increasing and has prompted consideration of closing the high seas entirely to harvest (*12*). In recognition of these issues, the UN adopted a landmark resolution in June 2015 that commences negotiations toward a treaty to better manage high-seas biodiversity (*2*, *7*, *13*).

S-AIS provides a low-cost global mechanism for making such a treaty meaningful and enforceable. To provide a first illustration, we summarized 648,591 S-AIS messages transmitted during 2014 of purse seine vessels working across 26 million km^2 of high seas in the tropical Pacific (*4*). Purse-seiners represent the largest commercial fishery in this high-seas region. S-AIS revealed hot spots of purse seine activity surrounding both the Galapagos Marine Reserve and PIPA (fig. S8).

There are many ways by which AIS could improve marine science and management beyond tracking fishing. AIS provides data about diverse ocean users, from cargo vessels to whale-watching boats, that can be used to develop zoning solutions that maximize biodiversity gains while minimizing industry impact (*14*). Additional AIS applications include use by sustainable seafood certifiers wishing to promote fisheries that transparently share harvest data, governments fulfilling seafood traceability requirements, local authorities aiming to decrease collisions between ships and marine megafauna, and overseeing development of seabed mining operations.

LOOPHOLES, POLICIES, AND PRIVACY. Fully reaping the benefits of AIS for ocean governance depends on correcting two key weaknesses: (i) only a small fraction of vessels are currently required to carry AIS; and (ii) some vessels that carry AIS cheat by turning off transponders, falsifying positional data, or transmitting improper identification data. Data analytics can play a major role in correcting AIS noncompliance. Newly developed algorithms can process data from thousands of ships to flag events when AIS has been switched off at sea. Other "despoofing" algorithms use diagnostic behaviors to determine the true purpose of misrepresented vessels (e.g., circular tracks to identify purse seine fishing) and correct falsified tracks (*4*, *9*). About 28 satellites capable of receiving AIS messages are in low-Earth orbit, with the launch of ~60 more low-cost micro- and nanosatellites planned in coming years (*4*). Such additions are a major step toward continuous global AIS coverage.

Although increased coverage and clever analytics can strengthen AIS, policy interventions are also required. First, the IMO should increase the strictness of its AIS regulation and require that all commercial fishing vessels ≥15 m, as well as all vessels >100 gross tonnes (regardless of industry and destination) be equipped with publicly accessible, tamper-resistant AIS systems. The 171 IMO member countries need then to collectively adopt these minimum IMO standards. Nations have codified the currently lax IMO AIS regulations with varying degrees of strictness (fig. S13 and table S4). For example, the European Union (EU) in 2014 mandated that all fishing vessels ≥15 m must carry AIS, and Mauritius and Ecuador require all fishing vessels to carry AIS. U.S. boats, however, are only required to carry AIS when fishing in the United States if they are ≥19.8 m and, when on the high seas, if they are ≥300 tons. Canadian fishing vessels are completely exempted from carrying AIS.

Second, each vessel carrying AIS should be required to obtain a unique IMO vessel identification number (*15*) that must be reported in all AIS transmissions and remain unchanged if a vessel reregisters or switches AIS hardware. Regional tuna management groups this year began to require IMO numbers for very large fishing vessels, but this remains optional for the many remaining vessels. In 2014, only 3.5% of self-identified fishing vessels reported a valid IMO number via AIS, making definitive vessel identification much more challenging and imprecise (*4*). Once assigned, vessel metadata need to be archived and shared in a regularly updated, publicly accessible system—for example, the UN Global Record of Fishing Vessels.

Finally, IMO member states and regional fisheries management organizations should

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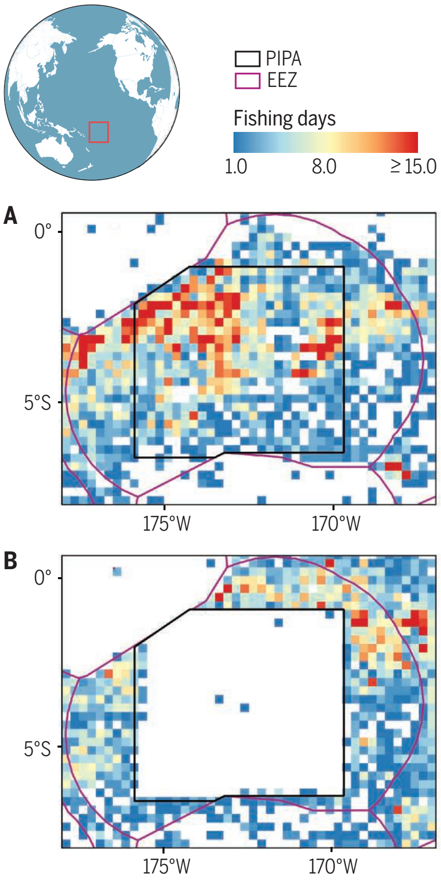
begin enforcing proper use of AIS. Simply having an AIS unit aboard a vessel, but failing to use it properly, can no longer be viewed as legal compliance. As noncompliance becomes better controlled, we also encourage that AIS data be more widely considered as admissible evidence in maritime judicial proceedings.

Evidence suggests that it is possible to equip all commercial fishing vessels in the world with AIS and enforce its use. About 75% of EU fishing vessels complied with 2014 AIS mandates within months (*9*). We estimated that 71% of large fishing vessels (>24 m) worldwide use AIS, and we observed a 17% increase in global AIS coverage for fishing vessels during 2014 (*4*). Closing remaining gaps among users resistant to compliance will be difficult but critically important.

Widespread implementation of publicly accessible AIS would effectively bring an end to the era of marine anonymity. There is growing awareness in marine and terrestrial sectors that benefits for human and environmental safety derived from observation technologies outweigh costs of renegotiating the boundaries of industrial privacy. Recognizing these values, the marine shipping industry has almost universally adopted AIS, as well as supplemental data-sharing systems.

Reforms under way to begin managing the ocean at vastly larger and ecologically meaningful scales will only matter if we can see and act on what is happening in these spaces. Transparency is an extremely important part of this process. Parallel closed-access tracking systems can and should be linked to AIS to improve our view of vessel activity, but closed-access systems allow only part of the picture to be seen by few actors and, consequently, have more limited value to science and transboundary biodiversity management. Unfortunately, current lack of legislative support for AIS has stunted this system into a service that best observes vessels that don't mind being seen. Although the policy shifts we call for require brave revisioning of the primacy of privacy on the oceans, failure to close loopholes will continue to foster illegal activities that steal income and biodiversity from developing nations, promote social injustice at sea, and undermine efforts to cooperatively manage the sustained vitality of our shared marine resources. ■



Observing marine protected areas from space. Summary of long-line and purse seine fishing as measured using S-AIS data in PIPA during the 6 months before (**A**) and 6 months after (**B**) it was closed to commercial fishing by the Kiribati government on 1 Jan 2015 (*4*).

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MICROBIOLOGY

The invisible dimension of fungal diversity

Can microbial taxa be defined from environmental molecular sequences?

By **David Hibbett**

Taxonomy plays a central role in understanding the diversity of life, translating the products of biological exploration and discovery—specimens and observations—into systems of names that capture the relationships between species. Taxonomic names facilitate communication among scientists and the public and provide conceptual handles for complex phylogenetic hypotheses. However, taxonomy can be challenging, particularly for fungi and other microorganisms, which are morphologically simple and extremely diverse (*1*). Molecular environmental surveys have revealed previously unknown branches of the fungal tree of life (*2*–*5*) and illuminated biogeographic patterns across all groups of fungi (*6*, *7*). Yet the products of this research are not being translated into formal species names, in part because of the very rules designed to facilitate taxonomy.

Two recently recognized groups of fungi, Archaeorhizomycetes and Cryptomycota, illustrate the magnitude of ongoing molecular species discovery. Archaeorhizomycetes are root-associated soil fungi that have been found in more than 100 independent studies. When Menkis *et al.* (*3*) pooled environmental sequences of ribosomal internal transcribed spacer (ITS) genes, they found 50 lineages of Archaeorhizomycetes containing at least two independent sequences with 97% similarity, a standard cutoff for recognizing OTUs (operational taxonomic units, often equated with species). They also found 95 unique sequences (singletons). Thus, as many as 145 species of Archaeorhizomycetes have been discovered. But only two have been formally named, *Archaeorhizomyces finlayi* and *A. borealis*, based on the only live cultures obtained so far (see the figure).

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