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EDITORIAL

Remote sensing and the UN Ocean Decade: high expectations, big opportunities

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doi: 10.1002/rse2.241

This year officially marks the beginning of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030)—the Ocean Decade. A primary objective of this coordination framework is to support scientific research and technological developments that can contribute to the conservation and sustainable management of the world's oceans. One of the seven Decade Outcomes is to secure healthy and resilient oceans where marine biodiversity is mapped and protected; however, fulfilling this goal will require data, knowledge, and technology. The use of remote sensing is now established in marine research and management and is crucial in developing our understanding of ocean patterns and processes at multiple spatial and temporal scales (e.g., Jawak et al., 2015). As such, remote sensing technology is expected to play a critical role in achieving the vision set by the Ocean Decade.

In the last 20 years, technological developments in remote sensing have boosted our ability to monitor the distribution and status of previously understudied ecosystems, from tidal flats and mangroves (Goldberg et al., 2020; Murray et al., 2019) to continental shelves (Pygas et al., 2020) and the deep sea (Lim et al., 2021). These developments have also enabled the mapping of marine physical and biogenic habitats and ecosystems at spatial resolutions never achieved before. For example, Lyons et al. (2020) recently demonstrated how coral reef habitats ranging from individual reefs (~200 km^2) to entire barrier reef systems (200 000 km^2) could be mapped across vast ocean extents (>6 000 000 km^2) using global multiscale earth observations, generating high-resolution maps that can be used to support ecosystem risk assessments and to inform management. Deeper seafloor habitats can now be mapped and imaged at a centimeter scale using autonomous underwater vehicles and sensors like synthetic aperture sonars (e.g., Thorsnes et al., 2019). Maps produced by such efforts are invaluable communication tools; they have become key for data integration and synthesis to inform decision-making in a variety of contexts (Guisan et al., 2013; Harris & Baker, 2020). These mapping exercises can also be used to predict the distribution of species, communities, or ecosystems based on their associations with the physical and chemical characteristics of the environment and can support seascape ecology studies that relate spatial patterns with ecological processes (Pittman, 2018).

Passive sensors mounted on unoccupied aerial vehicles (UAVs) and satellites are commonly used to map and monitor characteristics and components of the marine environment, such as sea surface temperature, salinity, marine mammal distribution, primary productivity, and harmful algal blooms (Pettorelli, 2019). Satellite radar altimeters have also long been used to study the oceans and derive coarse-scale digital bathymetric models (e.g., Dixon et al., 1983). The information compiled by different sensors can then be integrated to delineate broad marine biogeographic units such as ecoregions (e.g., Sayre et al., 2017; Spalding et al., 2007). At finer scales, UAV-mounted lidar sensors have enabled increased aboveground biomass monitoring in coastal systems such as mangroves (e.g., Qiu et al., 2019), while bathymetric lidar systems have boosted data collection efforts in submerged coastal areas, where it is often too dangerous and resource intensive to collect acoustic data and challenging for radar altimeters to differentiate land from water (Sandwell et al., 2002).

While active underwater cameras mounted on remotely operated vehicles or towed or dropped platforms have been extensively used to collect species and seafloor data and create photomosaics of the seafloor (e.g., Jones, 2009; Sward et al., 2021), optical remote sensing is usually limited to shallow and optically clear waters. This means

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that, in most situations, acoustic remote sensing represents the most effective source of data for ecologists interested in marine biodiversity. Acoustic remote sensing can be passive (i.e., using hydrophones to capture sounds in the environment) or active (i.e., using sonars that produce directional sound and listen for returns); both have their place in support of marine ecology and conservation. For example, multibeam echosounders enable the production of high-resolution digital bathymetric models, from which different terrain attributes (e.g., slope, rugosity) known to be direct or indirect surrogates of species distributions can be derived (Lecours et al., 2015, 2016; McArthur et al., 2010). Multibeam backscatter data and sidescan sonar imagery can also provide information about the distribution of sediment and seafloor habitat characteristics important to many species. Most often used in fisheries, singlebeam echosounders can provide critical information about what lives in the water column, while passive acoustic remote sensing can contribute species occurrence and distribution data and inform abundance and behavioral research (Stowell & Sueur, 2020).

There is no doubt that the UN Ocean Decade will provide exciting opportunities for the field of remote sensing and its applications to marine and coastal environments. Active acoustic remote sensing technologies have historically been associated with military uses and the field of hydrography rather than with the remote sensing community of practice; this has slowed the integration of data processing and analysis methods that have proven effective in the study of terrestrial environments. This gap offers new research opportunities that remain unexplored in marine environments. For example, because raw multibeam echosounder data are displayed as point clouds that share many characteristics with lidar point clouds,

Table 1. A meta-analysis of original research articles published in *Remote Sensing in Ecology and Conservation* highlights an increase in coastal and marine studies and a strong reliance on optical remote sensing and, to a lesser extent, passive acoustics.

References	Topics	Remote sensing approaches
Weishampel et al. (2016)	Mapping of sea turtle nesting patterns in Florida	Satellite-based visible and infrared sensors
Asner et al. (2017)	Coral reef mapping	Satellite multispectral imagery
Lecours et al. (2017)	Assessment of artifacts in marine habitat maps and species distribution models	Multibeam echosounder bathymetric and backscatter data
Di Iorio et al. (2018)	*Posidonia oceanica* meadows monitoring	Hydrophones (passive acoustic monitoring)
Ettritch et al. (2018)	Coastal sand dunes monitoring	Archived satellite data and aerial photography
Nahirnick et al. (2019)	Seagrass habitat mapping	UAV imagery
Rahman et al. (2019)	Mangrove forests mapping	Satellite multispectral imagery and radar data
Wedding et al. (2019)	Predictions of coral fish assemblages	Satellite multispectral imagery and topo-bathymetric lidar data
LaRue et al. (2020)	Coastal habitat mapping of Weddell seal	Satellite multispectral imagery
Bolin et al. (2020)	Entanglement of humpback whales in coastal environments	Satellite-derived sea surface temperature
Roca and Van Opzeeland (2020)	Characterization of underwater acoustic biodiversity	Acoustic recorders (passive acoustic monitoring)
Schroeder et al. (2020)	Nearshore kelp beds monitoring	Satellite multispectral imagery
Cubaynes et al. (2020)	Measuring whale skin spectral reflectance	Spectroradiometer
Ridge et al. (2020)	Intertidal oyster reefs mapping	UAV imagery
Lyons et al. (2020)	Coral reef mapping	Satellite multispectral imagery, airborne hyperspectral sensor, satellite-derived bathymetry, bathymetric data compilations
Soto et al. (2021)	Estimating animal density in three dimensions	Theoretical passive acoustic detectors and cameras
Ellis et al. (2021)	Marine habitat mapping	UAV imagery
Aldous et al. (2021)	Coastal wetland mapping	Satellite multispectral imagery and radar data, UAS imagery
Fretwell and Trathan (2021)	Coastal emperor penguins colony mapping	Satellite multispectral imagery
Ventura et al. (2021)	Characterization of underwater worm colonies	Underwater multispectral sensor
Poursanidis et al. (2021)	Marine habitat mapping	Satellite multispectral imagery, satellite-derived bathymetry, underwater camera
Sward et al. (2021)	Producing density estimates for the long spined urchin	Stereo video from a remotely operated vehicle, archived multibeam bathymetric data

Articles are listed chronologically.

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acoustic data processing workflows might benefit from algorithms developed for processing lidar data. The opposite is also true; the commonly used CUBE (Combined Uncertainty and Bathymetry Estimator) algorithm for the generation of digital bathymetric models and the combined storage of bathymetry and uncertainty layers within a single BAG (Bathymetric Attributed Grid) file format may benefit other types of remotely sensed data like lidar-derived digital surface and terrain models. Data fusion techniques offer opportunities for the production of seamless digital surface models spanning the terrestrial and marine environments that combine both optical and acoustic remotely sensed data (e.g., Linklater et al., 2018). New developments in image processing tools, analytical methods like object-based image analysis, and artificial intelligence have the potential to enhance marine ecology and seascape ecology research (Pittman et al., 2021). New ways to study the marine environment, such as multibeam water column data (e.g., Schimel et al., 2020), multispectral acoustic systems (e.g., Brown et al., 2019), and satellite-derived bathymetry (Ashphaq et al., 2021), highlight the need for more research into how remote sensing can contribute to the understanding and conservation of the world's oceans.

The issues targeted by the Ocean Decade, such as climate change and unsustainable exploitation of marine resources, are global and, as such, will require collaborative efforts and data from around the world. However, both ocean science and remote sensing capacities are unevenly distributed. Mapping marine ecosystems and biodiversity in places or through organizations that cannot count on well-funded initiatives must rely on existing, publicly available datasets such as the GEBCO (General Bathymetric Chart of the Oceans) global bathymetric dataset, archived satellite imagery, or marine biodiversity datasets like those compiled on OBIS (Ocean Biodiversity Information System). This highlights the need for open-source multidisciplinary data in both remote sensing and the marine sciences that can be spatially integrated accurately; it also highlights the need for a common platform where information gathered by these communities can be shared and scientific agendas synchronized. Since its inception, the editorial board of *Remote Sensing in Ecology and Conservation* has welcomed contributions to coastal and marine ecology and conservation that rely on remote sensing (Pettorelli et al., 2015). In 2017, the editorial board made it a goal to increase their engagement with communities working in marine systems and acoustic remote sensing (Pettorelli et al., 2017). The number of published "original research" articles on coastal or marine environments has steadily increased every year since 2016, reaching 21% of all contributions in 2020 (Table 1). However, the use of active acoustic remote sensing is still underrepresented, with only one article published since the launch of our journal. With efforts like the Seabed 2030 Project, which aims to map the world's seafloor by 2030 and relies heavily on acoustic remote sensing technologies (Mayer et al., 2018), we expect the availability of seafloor data to increase and, with them, the opportunities to better understand the ecology of our seas and oceans. We thus want to reiterate our commitment to marine remote sensing developments and applications and hope that the increased opportunities will be reflected in the submissions to come.

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