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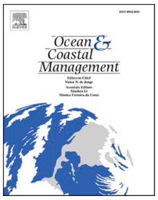

Review

A review of geospatial technologies for improving Marine Spatial Planning: Challenges and opportunities

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ABSTRACT

Common marine spatial planning challenges include lack of data on the marine environment, high mobility of both animals and humans, and plan implementation challenges including lack enforcement and compliance with regulations along with monitoring deficiencies. These can be potentially addressed using geospatial technologies (GTs) such as remote sensing, GPS and GIS. This research presents geospatial tools that are available for the process of developing, implementing, and monitoring marine spatial plans. Tools include satellites and water-based platforms carrying various sensors and receivers for environmental ocean data, vessel tracking and animal telemetry via multispectral, acoustic, radar, and other means. Planners and ocean managers might not always be aware of technological solutions available for the development and implementation of marine spatial plans. Here, urgent planning needs, summarized from various publications, are linked to GTs solutions published in relevant literature between the years 2015–2020. The GTs were used for data collection, dynamic human activities' management, environmental monitoring and enforcement, all as required by marine spatial plans. This paper concludes with insights into GT solutions that can enhance the process of evidence-based management and spatial planning in marine environments.

1. Introduction

The ecosystem-based management (EBM) approach to ocean management has been recognized as a leading approach for the management of ocean uses; marine spatial planning (MSP) has been recognized globally in recent years as a primary tool for implementing EBM (Álvarez-Romero et al., 2011; Ansong et al., 2017; Domínguez-Tejo et al., 2016; Ehler and Douvere, 2009; Fluharty, 2019; Gilliland and Laffoley, 2008). However, achieving the social, economic, and environmental objectives of the EBM approach in MSP encounters hardships when put into practice (Ansong et al., 2017; Frazão-Santos et al., 2018; Tallis et al., 2010).

The MSP process is data-dependent, yet it faces challenges with regard to data collection because it deals with the ocean and its dynamic properties, affecting the distribution of economic, social, biological, and oceanographic elements (Dunn et al., 2016; Gazzola et al., 2015; Kidd and Ellis, 2012). Fortunately, various recent scientific and technological advances have the potential to address these challenges, specifically geospatial technologies (GTs) (Fig. 1), which collect or process location-associated data (AAAS, 2018).

This paper discusses how geospatial technologies can enhance MSP practices and it indicates at which stage in the MSP process GTs can best be used. Ehler and Douvere (2009) divide the MSP process into three main parts: pre-planning, planning, and post-planning stages. Since the pre-planning stage includes securing authority and funding for the plan and is unrelated to the technological solutions offered here, it will not be discussed further. In this paper, we discuss the planning stage that relates to a planning team's data collection efforts aimed at understanding existing conditions and to the development stage of a management plan designed to accomplish pre-determined goals. The post-planning steps we will also discuss are the implementation stages that ensure compliance with and enforcement of the management plan, as well as monitoring which is required for evaluating the plan's success in achieving its goals (Ehler and Douvere, 2009).

Many of MSP challenges commonly reported in literature as encountered during the planning and post-planning stages (Table 1) could have a potential technological solution (as opposed to a solution requiring policy or regulatory change). Some of those specific challenges are limited data availability, including limited environmental data (Domínguez-Tejo et al., 2016), species distribution (Fabbrizzi et al., 2020; Katsanevakis et al., 2017; Levin et al., 2014; Rahman et al., 2019; Wilson et al., 2009), habitat maps (Bronwyn et al., 2016; Gerovasileiou et al., 2019; Giakoumi et al., 2013), bathymetric data (GEBCO Seabed 2030 Project, 2020; Hell et al., 2012; Levin et al., 2014), and deep-sea environment (below 200 m) related data (Danovaro et al., 2017; Grehan et al., 2017; Jansen et al., 2018; Thurber et al., 2014). Other challenges are associated with spatial and temporal ocean dynamics not fully included in MSP, exclusion which may result from MSP's static

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management approaches to dynamic human uses and fauna, but also from lack of full, up-to-date data on these constituents and their distribution, enabling a more spatiotemporal- sensitive approach (Agardy et al., 2011; Gissi et al., 2018; Lewison et al., 2015; Martin and Hall-Arber, 2008; Stamoulis and Delevaux, 2015; Zaucha and Gee, 2019). For implementation of MSP, challenges are a lack of effective enforcement (Agardy et al., 2011; De Santo, 2013; Ehler and Douvere, 2009; Policy Research Corporation, 2011; Portman et al., 2013; UNEP & GEF-STAP, 2014) (enforcement that could be better targeted with improved knowledge of human spatiotemporal activities) and unsatisfactory monitoring of the marine management plan area (Frazão-Santos et al., 2018; Mccann et al., 2014; Policy Research Corporation, 2011; Portman et al., 2013; UNEP & GEF-STAP, 2014).

Geospatial technologies stand out for their potential to address these marine planning challenges as they are used to acquire, manipulate, and store geographic information (AAAS, 2018; Dempsey, 2014). They enable the detection, collection, and analysis of multiple levels of spatial data, including physical, chemical, and biological components which not only facilitate MSP but align with achieving the sought-after EBM objectives, i.e., economic benefits, ecosystem health, conservation, and natural resource management (Kirkfeldt, 2019; Martin and Hall-Arber, 2008). Commonly used GTs are remote sensing, global positioning systems (GPS), and geographic information systems (GIS) (Fig. 1). Remote sensing refers to collecting images and information from afar, including not only satellite images but also scanning technologies such as sonars used to create seabed maps. GPS are satellite-based geolocation systems accessible worldwide to the public (enabling tracking of mobile human uses and tagged mobile marine fauna), and GIS enables the creation, organization, and presentation of data in a spatially referenced form as well as the production of maps and charts.

Previous papers on geospatial technological solutions do not address the complete set of GT tools and for the most part focus narrowly on remote sensing (El Mahrad et al., 2020; Fingas, 2018; Hedley et al., 2016; Ouellette and Getinet, 2016; Verfuss et al., 2019) or on a single technology in relation to MSP uses (Le Tixerant et al., 2018; Lee et al., 2019). Here, we decided to leave GIS and web mapping services out of the literature review, since in contrast to other geospatial technologies, these types of tools have been widely reviewed in the past for planning and for specific MSP needs (Depellegrin et al., 2017; González et al., 2020; Lathrop et al., 2017; Noble et al., 2019; Shaowen et al., 2019; Snickars and Pitkänen, 2007; Stelzenmüller et al., 2013; Trouillet, 2019); it is the extent to which all other GTs are being used for MSP that falls short. This paper aims to show how GT-derived data addresses the common limits associated with MSP in each planning stage i.e., for the following stages: supporting data collection, developing a spatiotemporal change-sensitive plan, enforcing and monitoring the plan. The importance of this review focuses on how GTs explicitly address the needs of MSP practitioners, planners, and ocean managers by mapping important tools available to them, thus promoting planning for scientific evidence-based ocean use.

2. Methods

2.1. *Evidence-based review on geospatial technologies (GTs)that are useful for MSP*

We conducted an evidence-based literature review to identify papers providing information about which GTs are available and how they are used in the marine environment. This type of review looks for evidence within the literature on how different GTs and data generated by them could assist particular aspects of MSP: for data collection, development of a plan that considers spatiotemporal changes, enforcement, and monitoring of the plan's management area. An evidence-based review is a transparent, repeatable, objective way to gain insight about the relevant literature (O'Leary et al., 2015). Here, particular aspects (years, the number of databases, language) are stipulated in advance thus limiting the review and rendering it "rapid". A rapid evidence-based literature review is a useful tool to conduct research in a timely manner. Here, mostly, we wanted to limit our search to include only novel technologies from the past five years (2015–2020). Such a rapid review is less deep

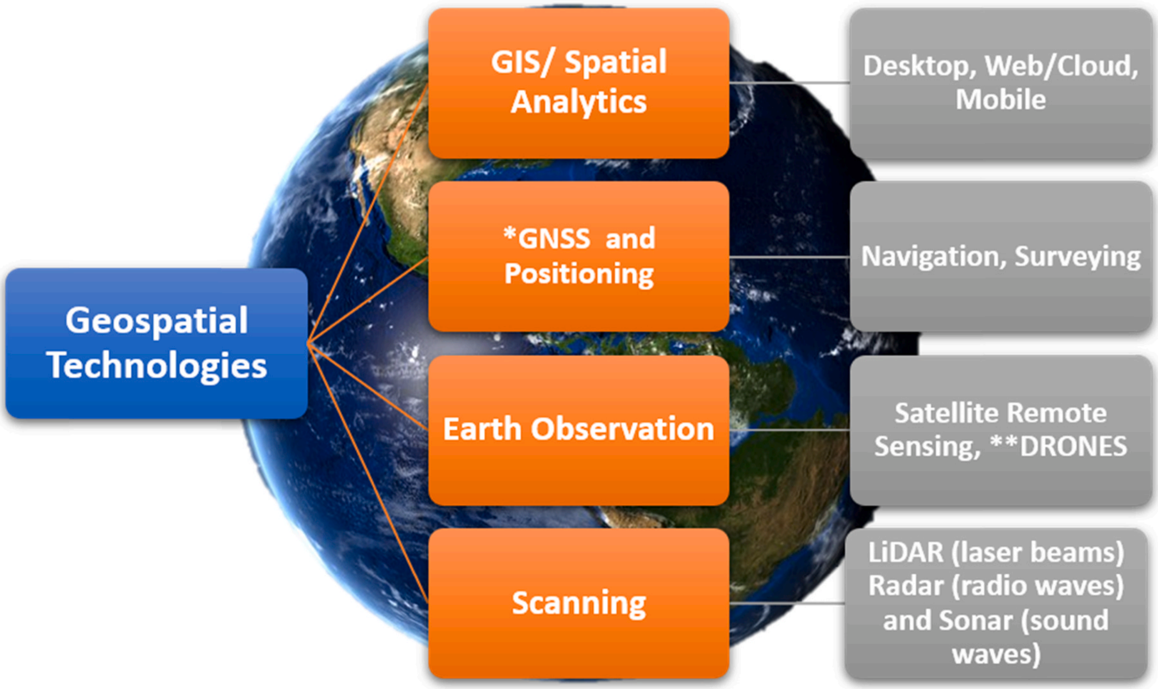

Fig. 1. Current geospatial technologies (orange) with common examples (grey). * Global Navigation Satellite System (GNSS), including GPS. ** Dynamic Remotely Operated Navigation Equipment (image adapted from https://www.geospatialworld.net/).

Table 1
MSP challenges as appearing in the literature.

MSP Step	Common Challenges	Source
Defining and analyzing current conditions	• Time-consuming • Timeliness of data • Lack of data	Collie et al. (2013) (Hobday and Hartmann, 2006; Shucksmith and Kelly, 2014; Welch and Mchenry, 2017) (Ban et al., 2010; Bronwyn et al., 2016; Buhl-Mortensen et al., 2017; Danovaro et al., 2017; Diaz et al., 2004; Domínguez-Tejo et al., 2016; Fabbrizzi et al., 2020; GEBCO Seabed 2030 Project, 2020; Gerovasileiou et al., 2019; Giakoumi et al., 2013; Grehan et al., 2017; Halpern and Fujita, 2013; Hell et al., 2012; Jansen et al., 2018; Katsanevakis et al., 2017; Levin et al., 2014; Lombard et al., 2019; Rahman et al., 2019; Thurber et al., 2014; Wilson et al., 2009)
Management plan development	Static zoning inadequate for dynamic environment	(Agardy et al., 2011; Corbane et al., 2015; Cumming et al., 2006; Dunn et al., 2016; Game et al., 2009; Gazzola et al., 2015; Hazen et al., 2018; Lewison et al., 2015; Maxwell et al., 2015, 2020; Portman, 2016; Ritchie and Ellis, 2010; Siders et al., 2016; Stamoulis and Delevaux, 2015)
Management plan implementation	• Achieving compliance with regulations for activities • Lack of funds and trained personnel	(Arias et al., 2015; Arias and Sutton, 2013; Bergseth et al., 2017; De Santo, 2013; Elvidge et al., 2018; Game et al., 2009; Moutopoulos et al., 2019; Pieraccini et al., 2017; Silber et al., 2014; UNEP & GEF-STAP, 2014) (Ali and Abdullah, 2010; Ciminoet al., 2019; Game et al., 2009; Garrison and Rollinson, 2015; Greenpeace, 2007; Silber et al., 2014)
Plan execution monitoring and evaluation	Achieving satisfactory monitoring of indicators	(Borja et al., 2016; Christie et al., 2017; Douvere and Ehler, 2011; Ehler, 2014; FAO, 2015; Giakoumi et al., 2013; Lockhart et al., 2012; NOAA, 2003; Policy Research Corporation, 2011; Stamoulis and Delevaux, 2015; Terrill et al., 2015)
Adaptation of the plan	Rarely been implemented, partially because of unsatisfactory monitoring	(Collie et al., 2013; Domínguez-Tejo et al., 2016; Ehler and Douvere, 2009; Gissi et al., 2018)

and does not include everything published on the topic however, we considered it efficient for our research goal, since this method summarizes available evidence, highlighting what is already known (Barends et al., 2017; Daykin & Creative and Credible Project team, 2015; Grant and Booth, 2009; O'Leary et al., 2015), thus providing a firm understanding of what technologies exist and are currently in use. Our review uses the ISI Web of Science database as its source of information.

2.1.1. *Inclusion and exclusion criteria*

We used the evidence-based review to locate research that presents first-hand results (i.e., that produces primary sources of data) with GTs used in a manner consistent with MSP's needs (see Table 1). The reason for excluding sources such as reviews and opinions was that we did not want to get repetitive results in a manner that those types of sources cited other original research (i.e., leading to "double counting") (Table 2).

The search terms were carefully selected after many trials and errors. The particular search terms we chose connect GTs and marine-related planning activities. As such, queries used to identify GTs included either of the terms (or combinations of) "remote sensing, satellite, GPS, drone, glider, AIS, VMS" combined with "marine, maritime, MPA, ocean, sea" and any words containing "plan, fisher, manage, monitor" with "biodiversity, conservation, compliance, mitigate" and "tech, system, method, evaluate, measure". We excluded terms referring to the integration of coastal landscapes such as river, delta, coast, marshes, mangroves because we were interested in identifying exclusively marine activities. We also excluded papers that were not published between the years 2015–2020 in order to target the latest technologies.

The method we used for choosing the specific search terms to cover as a wide as range of technologies as possible for sectors relevant to MSP consisted of using all the search terms and then subsequently removing them one by one to assess which search terms were already included or addressed by others, thus focusing the search results to the most relevant papers. For example, the term "remote sensing" returned papers using acoustic monitoring techniques, covering bathymetric mapping needs, oil and gas seismic surveys, and passive acoustic monitoring. The term "AIS" retuned marine traffic related data, including the shipping, tourism, and fisheries sectors. VMS specifically addressed fisheries. Aquaculture was addressed in papers using earth observation satellites. Similarly, renewables, like wind farms, were not specifically noted in the search query since the spatial considerations for their development areas are addressed under the rest of the keywords chosen which covered displacement of human activities, habitat effects, and collision risks.

We filtered the search query results (see Fig. 2) by excluding articles belonging to irrelevant ISI Web of Science categories (categories represent research fields, i.e., categories such as "physics nuclear", "limnology", "clinical neurology" were excluded from scanned results). Then, titles and abstracts were screened, eliminating records irrelevant to the topic or that did not involve an empirical approach; empirical defined as cases where data was gathered or analyzed primarily by the authors (Table 2). Full-text papers remaining were screened and classified for (1) particular GTs used, (2) purpose, (3) outcome (e.g., successfully achieving a specific target), (4) stage of the planning process we believe these methods could enhance. Out of the full-text papers reviewed, papers were eliminated if they did not use an empirical method, GTs were not the primary tool relied on, or if research

Table 2
Eligibility criteria used in guiding this review via the ISI Web of Science database.

Criteria	Inclusion criteria	Exclusion criteria
Years published	2015–2020	Published before 2015
Language	English	Not English
Type of document	Published peer-reviewed original empirical (first-hand results) research	Review, non-empirical, opinion, concept paper, conference paper, book chapter, book, report (i.e., grey literature), short communication, editorial
Area	Marine/Ocean	Terrestrial, freshwater, only coastal
Technology	Geospatial	Not including geospatial tools in research as main tool
Relevance to the MSP field	Relevance to planning, managing, conserving, monitoring in the marine environment	

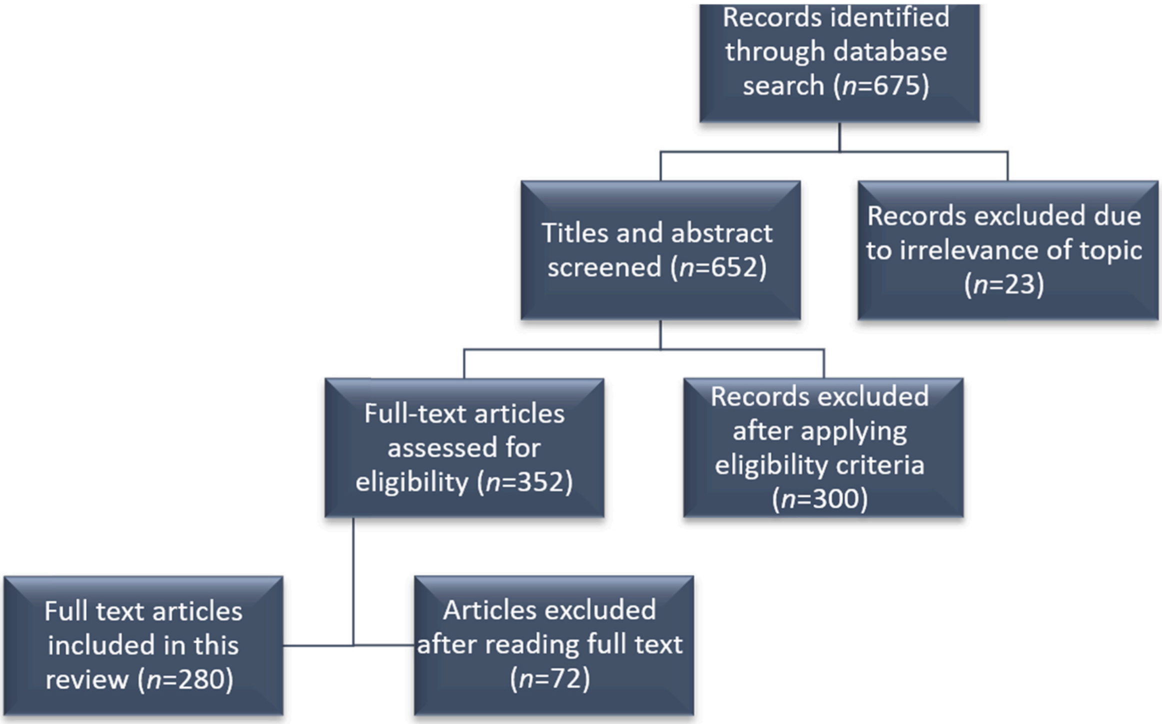

Fig. 2. The stages in the evidence-based review, including the number of papers (*n*) reviewed at every stage.

conclusions did not show relevance to the planning process.

3. Results

3.1. Evidence-based review of geospatial technologies relevant to MSP

Our review identified papers using GT-derived data that can support common MSP challenges (Table 3). We categorized full-text papers ($n = 280$) (Supplementary material A) by the MSP challenge or gap addressed by each GT solution. The MSP challenges we addressed were (1) gathering and creating baseline data, (2) support of dynamic ocean management enabling a more spatiotemporal-sensitive approach to managing mobile human uses and mobile marine fauna conservation, (3) enforcement of regulations, and (4) enhanced monitoring techniques. Gaps relevant to the adaptation of plans were included in the monitoring stage because the adaptation of a marine plan requires satisfactory monitoring for proper evaluation of the plan's success in achieving its goals (Ehler and Douvere, 2009).

Table 3
MSP step, common challenges encountered by practitioners during that step (See Table 1), and the number of papers that use geospatial technological tools highlighting a solution to those challenges.

MSP Step	Common Challenges	Solution provided by GTs (n = number of papers)
Defining and analyzing current conditions	Time-consuming, timeliness of data, lack of data	Generating updated baseline data ($n = 205$)
Management plan development	Zoning as an inadequate approach in a dynamic environment	Dynamic ocean management supporting the refinement of temporal and spatial scale of managed areas ($n = 57$)
Management plan implementation	Achieving compliance with regulations for activities, lack of funds and trained personnel	Improved enforcement and compliance ($n = 26$)
Plan execution monitoring and evaluation	Satisfactory monitoring of indicators	Enhanced monitoring techniques ($n = 130$)
Adaptation of the plan	Rarely been implemented, partially because of unsatisfactory monitoring	Enhanced monitoring techniques (proper adaptations are supported by better monitoring options)

Among the papers included in this review, the most prominent topics were GT-derived data on the marine environment (such as oceanographic conditions) and human-animal interactions.

3.1.1. Description of the most commonly used technologies

Here, the geospatial marine data in the 280 papers selected for this review was gathered by various tools, mainly earth observation satellites (98 sources), biotelemetry either via acoustic or satellite-linked tags for animal tracking (96 sources), vessel tracking (AIS and VMS) (37 sources), passive acoustic monitoring (acoustic signature recordings of geophysical, biological and anthropogenic origins) (33 sources), active sonar surveys (21 sources) and autonomous vehicles with various sensors, operating from the air, ocean surface or underwater (15 sources). Fig. 3 shows these GTs and the relationship between them.

In the next six sub-sections we summarize the most common technologies appearing in the reviewed papers, for the reader to familiarize themselves with the type of data provided by each GT tool. Then, we give specific examples of when the GT or the GT-derived data is recommended for the planning and implementation stages. The aim is to clearly map out how to best utilize GTs for MSP.

3.1.1.1. Earth observation (EO) satellites. Satellites orbiting the earth gather high-resolution data on a global scale in a repetitive timely manner. There are active and passive satellites. Those that are passive observe natural radiation such as natural visible and infrared (IR) light and passive microwaves. Active satellites have their own illuminating energy that they send out as electromagnetic energy and then detect the return signal, like radars sending and receiving radio waves. The papers included in this review commonly used both active and passive satellite-derived data (Earthdata, n.d.).

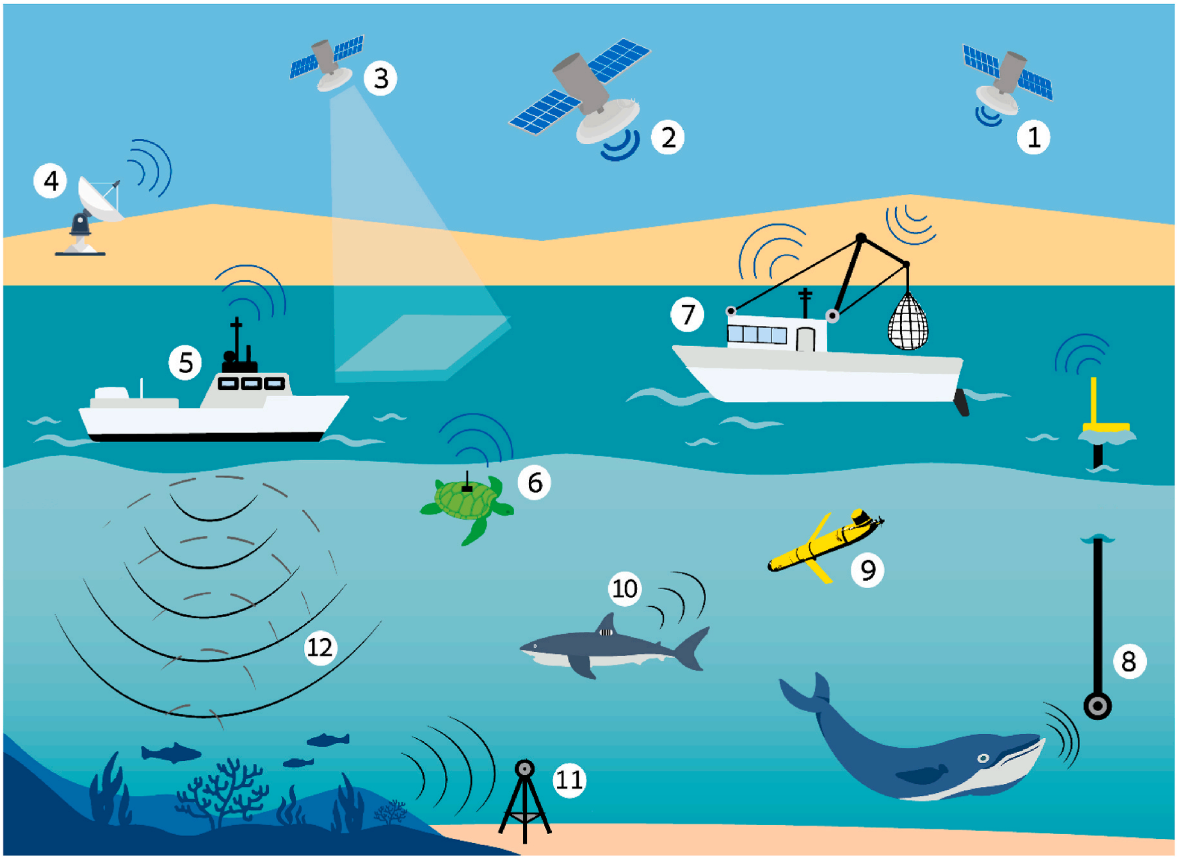

Fig. 3. Common geospatial technologies used in the 280 papers included for this review: (1) navigation satellite (2) communications satellite (3) remote sensing satellite (4) satellite ground station (5) automatic identification system (6) satellite biotelemetry (7) vessel monitoring system for fisheries (8) real-time passive acoustic (9) autonomous underwater vehicle (glider) (10) acoustic biotelemetry (11) passive acoustic recording of the soundscape (12) sonar. (Figure credit: Dana Schwartz).

Frequent examples of data types collected in a large scale, up-to-date manner using remote sensing satellites are sea surface height (SSH), sea surface salinity (SSS), and sea surface temperature (SST), as well as ocean water color interpreted into chlorophyll-a concentration, suspended solids, and turbidity. These detected oceanic conditions were used to identify areas suiting aquaculture, pelagic conditions ideal as hotspots for animal gathering or even to assess connectivity between habitats. Satellites are also used for classification of shallow benthic habitats such as coral reefs and seagrass meadows. Scientists report that identifying and monitoring such benthic habitats from space is labor-efficient, more precise and offers better coverage than on-the-ground methods (Earthdata, n.d.; Guo et al., 2015; Hobday and Hartog, 2014; Howell et al., 2008; Liu et al., 2020; Ouellette and Getinet, 2016; Schroeder et al., 2019; Smith and Bernard, 2020; Topouzelis et al., 2018). Visible infrared imaging radiometer suite (VIIRS) satellites detect night light and are used for identifying night fishing and for monitoring light pollution (Elvidge et al., 2015; Hsu et al., 2019; Ouellette and Getinet, 2016). Synthetic aperture radar (SAR) satellites detect objects on water surfaces such as ships. While SAR cannot penetrate the water surface as visible light does, it uses an active microwave sensor (radar signals), and therefore provides 24-h observations independent of light or good weather (Maurer, 2002; Ouellette and Getinet, 2016; Rowlands et al., 2019).

3.1.1.2. Animal biotelemetry. In biotelemetry, wildlife is tagged with a device that records and transmits data to remote stations, commonly through satellites or acoustic signals picked up by receivers. Satellite communication tags are mostly used on air-breathing fauna and acoustic tags on water-breathing fauna. The latter requires a sensor to receive the data, either a static one around an area of interest or a mobile one (i.e., on a vessel) following the signal (less common). The tags report animal locations, and movement is recorded without human interference or disturbance. Tags are available at various prices and sizes, making them a popular research tool. The tags can record environmental conditions (wind direction, current velocity, temperature, salinity, chlorophyll concentration) along with death or behavior such as swimming, feeding, diving, or flying. Data is provided from remote areas, great depths, or over long periods, allowing for time-space analysis for highly mobile fauna (Briscoe et al., 2016; Cazau et al., 2017; Edwards et al., 2019; Harcourt et al., 2019; Heylen and Nachtsheim, 2018; Jeantet et al., 2018; Maxwell et al., 2016).

Telemetry data reveal foraging habitats (Lombard et al., 2019; Stokes et al., 2015), spatial uses according to different life stages (Luschi and Casale, 2014; Pütz et al., 2016; Scott et al., 2012), main movements and migratory corridors, and even lack of the need for specific gathering spots or discernible home range which enables other less space-consuming management strategies (Hart et al., 2019; Oksanen et al., 2015; Stokes et al., 2015). Species distribution predictions used for conservation and fishery purposes are based on a link between environmental data and tagged species distribution (Bangley et al., 2020; Pérez-Jorge et al., 2020; Scales et al., 2017; Van Beest et al., 2018). Telemetry data allows for more accurate and fitting delimitations of conservation areas (Daley et al., 2015; Lea et al., 2016; Levy et al., 2017; Rowell et al., 2015). Crossing telemetric data with vessel-tracking data offers understandings of human-animal interactions (Pikesley et al., 2018; Queiroz et al., 2019; Sommerfeld et al., 2016; White et al., 2017). By looking into horizontal and vertical factors detected by telemetry, conflicts and compatibilities with fisheries are revealed, allowing more options for management measures (specific gear, depth, temporal requirements) to tackle these spatiotemporal overlaps (Bestley et al., 2016; Francis et al., 2015).

3.1.1.3. Vessel tracking systems (VMS/AIS). Vessel tracking data used in the review papers are based on the technologies called Vessel Monitoring System (VMS) and Automatic Identification System (AIS). VMS is a system operating only in commercial fisheries sectors for reporting fishing vessels' identity, location, and movement to the fisheries' regulatory authority in the country. Each fishery authority operated its own VMS system and the VMS data is confidential, to protect commercial fishers' fishing grounds from other fishers. Vessel monitoring systems usually only sends a location signal once every 1–2 h. Unlike VMS, the on-board AIS is an anticollision system which is not exclusively used by fishery management organizations but rather by any vessel that installs it for safety. The AIS messages are sent every 2 s to 3 min, depending on the specific maneuver or speed of the vessel and these signals are picked up by any AIS receptor within VHF radio range (receivers on other ships (ship-to-ship) and land-based receiving stations (ship-to-shore). AIS data includes the vessel's identity, position, course, and speed, and is publicly available for analyzing or tracking historical or real-time vessel movements.

Newer technology enables the detection of AIS signals from satellites. When satellites detect AIS signals, these are referred to as Satellite-AIS (S-AIS). The benefit of S-AIS signals detection is that they reach beyond VHF range, exposing former blind spots of land-based stations tracking vessels through AIS signals. The International Maritime Organization (IMO) requires that all ships over 300 gross tons engaged on international voyages, cargo ships over 500 gross tons not engaged on international voyages, and all passenger ships irrespective of size to be fitted with AIS (IMO, 2015). The European Commission requests fishing vessels 12 m and above to install a VMS and over the size of 15 m to also install AIS (European Commission, n.d.; Natale et al., 2015; "Satellites for safer seas," n.d.; Schill, 2015). Since vessel tracking systems monitor human activities, the location data allows assessment of compliance with different spatial regulations. Conflicts and compatibilities with other human uses and environmental disturbances can be identified from vessel tracking data (Chuaysi and Kiattisin, 2020; Silber et al., 2014; van der Reijden et al., 2018). For example, assessment of the extent of overlap between marine fauna habitats and fisheries or marine traffic (Guzman et al., 2020; Pikesley et al., 2018; White et al., 2019).

3.1.1.4. Active sonar (SOund NAvigation and Ranging). Active sonar sends out acoustic waves and then detects and analyses the returning signal, unlike passive sonar which only detects acoustic sounds omitted from the environment. By actively omitting sound waves, the acoustic location of targets is detected, including measurement of the target characteristics (NOAA, n.d.). Through a method known as echo sounding, an acoustic signal is sent directly down toward the seabed and depending on the time lapsed for its return, water depth is measured. Similar tools can characterize sea bottom types (gravel, sand, mud) (Boswarva et al., 2018). Acoustic surveys are common tools for habitat investigation and are critical for habitat mapping (Heinrich et al., 2017), which in turn can act as a proxy for data on biodiversity (Corbane et al., 2015).

Active acoustics are also used for detecting nekton and are widely used by the fishing industry to detect fish underwater (Cholewiak et al., 2017). Commercial sonars operate at different frequencies and beam spans depending on their operational target. Many commercial sonars operate well within cetacean hearing ranges, suggesting that anthropogenic disturbances for scientific and industrial purposes require careful consideration. Since active sonar is a disturbance, acoustic pings are also used to deter dolphins from fishing nets (Clay et al., 2019). Passive acoustic monitoring of fish has been suggested to estimate fish populations instead of active sonars (Hossain and Hossen, 2019).

3.1.1.5. Passive acoustic monitoring (PAM). The presence and activities of many animals emit acoustic signals (Gibb et al., 2019). Recording acoustic signals is a relatively cheap method for collecting data on the sound sources in the marine environment (Lindseth and Lobel, 2018; Parks et al., 2014). PAM is an ecosystem-based approach for assessing long-term changes in community abundance, richness, health, and diversity, primarily based on the aural identification of species (the sounds they emit). This approach is very popular in bioacoustic studies for targeted monitoring of focal species. Targeted research on specific animal sounds allows detection of seasonal habitat presence, the overtime complexity change in fish population, and reproductive cycles (Charif et al., 2020; Farina, 2018; Lindseth and Lobel, 2018; Siddagangaiah et al., 2019; Zemeckis et al., 2019). Marine mammals are commonly surveyed visually from ships, yet acoustic monitoring decreases bias since visual surveys are usually performed when there is good weather and cannot quantify deep water foraging (Baumgartner et al., 2019; Davis et al., 2017; Diogou et al., 2019; Giorli et al., 2016; Putland et al., 2018; Silva et al., 2019).

Soundscapes are a more holistic approach to acoustically describing a habitat. Instead of focusing on specific specie-emitted sounds, passive ecoacoustic monitoring (PEM) detects acoustics from physical parameters emitted from all environmental origins, not just biological ones but also geophysical (wind, waves, rain) and human sources. Soundscapes can compare between habitats (e.g., inside or outside of a marine protected area (MPA)) or over time at the same location (Bertucci et al., 2016; Desiderà et al., 2019; Farina, 2018; Pijanowski et al., 2011; Roca and Van Opzeeland, 2020). Ecoacoustics assesses deep water fish abundance and biodiversity, and habitat health, such as coral coverage. Acoustic monitoring is considered time-efficient, from individual species to landscapes, reflecting general ecosystem properties and ecological functioning over time and space (Akamatsu et al., 2018; Butler et al., 2017; Elise et al., 2019; Elise et al., 2019; Farina, 2018; Freeman and Freeman, 2016; Putland et al., 2018).

Acoustic recordings also enable noise detection from anthropogenic activities, such as marine traffic or seismic surveys (Enguix et al., 2019). Vessel acoustic detection methods are, among other uses, designed to assess high-risk areas, such as detecting vessels fishing inside no-fishing zones (Kline et al., 2020) and for impact assessment of activities generating intrusive anthropogenic-origin noise. Anthropogenic-origin noise is harmful to many species' well-being, including marine mammals, fish and turtles. A better evaluation of the impact of noise, such as from shipping, is achieved when vessel tracking data (as AIS) is coupled with vessel sound recordings in areas of interest (Gaggero et al., 2015; Rousset et al., 2016).

3.1.1.6. Unmanned air and sea vehicles. Unmanned platforms carry sonars, hydrophones for recording sound, cameras, or sensors for environmental data recordings. These platforms enable data gathering with lower costs for manpower and equipment and can be GPS-guided (Baumgartner et al., 2020; Brooke et al., 2010; Dunlop et al., 2018; Edwards et al., 2019; Maxwell et al., 2016; Pierdomenico et al., 2015). Aerial unmanned vehicles are used to count remote populations in a non-invasive way (Babatunde et al., 2020; Oosthuizen et al., 2020). Unmanned surface and underwater vehicles such as gliders equipped with hydrophones record and identify marine mammal communications and can monitor and alert the location of wildlife, some in near real-time (Aniceto et al., 2020; Baumgartner et al., 2020; Davis et al., 2016; Silva et al., 2019; Zemeckis et al., 2019).

The above reviewed GTs enable data detection from afar while complementing ground-truthing methods used today. While not the only method for data collection, GTs provide data that is accurate, varied in scale, and fits different marine environments. Through the use of these technologies, policies that rely on such marine ecological and social data could be more accurate and inclusive (SEDAC, n.d.).

3.2. Recommended use of geospatial technologies for marine spatial plan development and implementation

In this section, the reviewed literature is organized to show how to best utilize GTs for informed decision making and management. End-user needs are highlighted in Table 4 through 7 and then linked to the papers showcasing each technology. The tables show how some of the more common MSP gaps could be addressed using GTs. Table 4 highlights GTs that aid in collecting data on the marine environment and of human uses and suggests which of those technologies could also be used for monitoring these environments and uses. Some papers utilize existing data and cross different GT derived data to assemble new insights, other papers use GTs to create new data by gathering it themselves. Table 5 highlights GTs that support data collection for more flexible management approaches, in time and space, and suggest which of those GTs are relative also for baseline data gathering. Table 6 highlights GTs that support enforcement by surveilling human uses at areas requiring compliance with existing regulations and suggests which GTs have other added uses (such as for data gathering and monitoring). Table 7 highlights GTs that are useful for monitoring goodness of fit of newly allocated conservation areas, success of mitigation activities, and also of targeted habitats and species' current condition in specific human impacted areas.

Table 4
Sources on geospatial technologies derived data that can be used for baseline data gathering. DOM (Dynamic Ocean Management).

	Use	Technology type	Example	References	Added use
Defining and analyzing current conditions: Baseline data	*Detection of areas for specific human use*	EO Satellites	Choosing areas for aquaculture that are less susceptible to risk and identifying aquaculture use areas	(Liu et al., 2020; Smith and Bernard, 2020)	Monitoring
			Ice patterns in the arctic to determine access to hunting grounds for indigenous people	(Lovvorn et al., 2018)	Monitoring
			Spatial conflict/compatibility between humans and mobile fauna	(Hutchinson et al., 2019; Kowarski et al., 2018)	Monitoring
		AIS/VMS	Spatial and temporal seasonal variability of fishing effort, identifying fishing grounds	(De Souza et al., 2016; Le Guyader et al., 2017)	Monitoring
			Vessel pressure	(Omeyer et al., 2020)	
		AIS + EO Satellites	Predicting suitable fisheries pelagic habitats on the high seas	(Crespo et al., 2018)	
		Active acoustic survey (sonar)	Distribution and abundance of krill	(Davis et al., 2017; Niklitschek and Skaret, 2016)	Monitoring
		Passive acoustics	Estimate the extant of human pressure in an area using underwater microphones (hydroacoustic) recording anthropogenic origin sounds	(Andre et al., 2016; Chan and Hodgson, 2018)	Monitoring
		Telemetry	Detecting megafauna conflict with vessels	(Hutchinson et al., 2019)	
		Telemetry + AIS/VMS	Detecting megafauna conflict with vessels	(Lucchetti et al., 2016; Pérez-Jorge et al., 2020)	Monitoring
Defining and analyzing current conditions: Baseline data	*Detection of important conservation management areas*	Telemetry	Connecting highly mobile animal spatial movements to predictive marine environment conditions, seasonal habitat suitability maps, dynamics of space use and horizontal movements	(Duffy et al., 2019; Hutchinson et al., 2019; Pérez-Jorge et al., 2020; Scales et al., 2016; Van Beest et al., 2018)	Monitoring and DOM
			Matching MPAs' borders with mobile animal movements and identifying hotspots for conservation	(Dujon et al., 2018; Hart et al., 2019; Honda et al., n.d.; Javed et al., 2019; Martín et al., 2020; Queiroz et al., 2020; Venables et al., 2020; Weng et al., 2015)	Monitoring and DOM
			Need for movement and migration corridors	(Hart et al., 2019; Horton et al., 2017; Stokes et al., 2015)	
			Adding depth data to understand habitat requirements	(Bestley et al., 2016)	Monitoring
		Passive acoustics + Telemetry	Spatial and temporal distribution of fish spawning	(Rowell et al., 2015; Zemeckis et al., 2019)	Monitoring
		Passive acoustics	Overlap of protected species with fisheries	(Prosdocimi et al., 2021)	Monitoring
			Foraging and breeding areas of marine mammals	(Carlén et al., 2018; Giorli et al., 2016; Temple et al., 2016)	Monitoring
		Telemetry + VMS	Overlap of protected species with fisheries	(Queiroz et al., 2016)	Monitoring
		EO Satellites	Habitat classification: Pelagic habitats and connectivity	(Crochelet et al., 2016; Davis et al., 2017; Muñoz et al., 2015)	
Defining and analyzing current conditions: Baseline data	*Mapping important biological and ecological areas*	EO Satellites	Estimating kelp biomass	(Tin et al., 2020)	Monitoring
			Habitat classification: Benthic habitat mapping: reef, kelps, seagrass	(Eugenio et al., 2017; Iqbal et al., 2019; Li et al., 2020; Pearman et al., 2020; Schroeder et al., 2019; Traganos et al., 2017; Traganos and Reinartz, 2018b, 2018c)	
		Active acoustic surveys (sonar)	3D complexity of coralline algae (Coralligenous) reefs	(Marchese et al., 2020)	Monitoring
			Distribution and abundance of Krill	(Watkins et al., 2016)	Monitoring
		Passive acoustics	Assessing biodiversity, richness, and abundance through soundscape indices	(Elise et al., 2019; Elise et al., 2019; Hossain and Hossen, 2019; Roca and Van Opzeeland, 2020; Siddagangaiah et al., 2019)	Monitoring
			Mobile fauna temporal distribution	(Diogou et al., 2019; Erbeet al., 2015; Kowarski et al., 2018; Temple et al., 2016)	Monitoring

Table 5

Sources indicating dynamic ocean management (DOM) capabilities.

	Use	Technology type	Example	References	Added use
Development of a management plan: Dynamic Ocean Management (DOM)	*Dynamic delimitation of conservation areas or management strategies for highly mobile species*	EO Satellites	Predicting bycatch events using oceanographic conditions	(Hahlbeck et al., 2017)	
		Telemetry	Matching MPAs' borders to highly mobile animal movements	(Bangley et al., 2020; Lea et al., 2016)	Baseline data gathering and monitoring
			Migratory routes	(Hart et al., 2019; Horton et al., 2017)	
		Telemetry + EO	Distribution of highly migratory species and habitat preferences	(Hazen et al., 2018; Pérez-Jorge et al., 2020)	Baseline data gathering
		Telemetry + AIS	Identifying high-risk areas for mega fauna	(Panigada et al., 2017)	Baseline data gathering
	Seasonal closure	Telemetry + passive acoustics	Spawning sites	(Rowell et al., 2015)	Baseline data gathering
	Human-animal interactions	Passive acoustics	Real-time alert on marine mammals' presence near boats to prevent collisions	(Brunoldi et al., 2016; Davis et al., 2016; Reis et al., 2019)	Baseline data gathering and monitoring
		Telemetry + AIS + EO Satellites	Fisheries and protected species overlap. Time-area closure needs	(Queiroz et al., 2019)	Baseline data gathering
		Telemetry	Dynamic relationship with fisheries and fish stocks	(Kindt-Larsen et al., 2016; McInnes et al., 2019; Sherley et al., 2017)	Baseline data gathering

Table 6

Sources indicating geospatial technologies use for enhancing compliance and enforcement at sea.

	Use	Technology type	Example	References	Added use
Plan implementation: Enforcement and compliance	*Compliance with regulation*	AIS/VMS	Compliance with slow zone to reduce whale-vessel strike risk	(Guzman et al., 2020)	
			Compliance with conservation area regulations/no trawl area	(Tassetti et al., 2019; Thoya et al., 2019)	Baseline data gathering, monitoring
			Detecting anomalous vessel behavior/indicators of IUU Fishing	(Chuaysi and Kiattisin, 2020; Ford et al., 2018; Miller et al., 2018)	
			Vessel alert system to promote compliance with MPAs	(Read et al., 2019)	
		EO Satellites: Visible Infrared Imaging Radiometer Suite (VIIRS)	Nighttime fishing detection	(Elvidge et al., 2015, 2018)	Baseline data gathering, monitoring
		EO satellite SAR (Synthetic Aperture Radar) + AIS	Detecting 'dark' targets and unregulated activities	(Kurekin et al., 2019; Rowlands et al., 2019)	
		Telemetry	Targeting patrol efforts against IUU to high-risk areas	(Jacoby et al., 2020)	Baseline data gathering and monitoring
		Passive acoustics	Vessel presence detection	(Chan and Hodgson, 2018; Reis et al., 2019; Ross et al., 2018)	Baseline data gathering

4. Discussion and conclusion

Geospatial technologies-derived data can be effective in helping practitioners and stakeholders recognize, manage and operationalize informed marine management. Initially, we addressed common MSP challenges encountered during marine spatial plan development and implementation stages; those challenges were lack of baseline data, static management for dynamic conditions, lack of enforcement of regulations, and unsatisfactory monitoring. The information provided in Tables 4–7 indicates how available geospatial tools could be used to support these MSP-related challenges. The papers cited show how GT and GT-derived data were used for collecting new data on the marine environment including on mobile fauna and human uses, and they show how this data could be of use to better allocate areas for certain activities by a marine plan. They also indicate how to incorporate spatiotemporal changes within the plan, counter regulation violators, and monitor a management plan's outcomes. This paper can assist practitioners in selecting appropriate GT-derived data to conduct marine spatial planning in their own jurisdictions and overcome some of the challenges mentioned above.

The first of four challenges we addressed was the lack of baseline data to assess existing conditions within the marine plan's scope. The GTs that were linked to baseline data gathering show a high contribution to conservation management. Such contributions include habitat detection and support the ability to match highly mobile marine fauna movements to protected or managed areas based on tagged animals' locations, predictive environmental conditions, and passive acoustic monitoring. This spatial "matching" supports allocated areas within a spatial plan such as MPAs, migration corridors, and core seasonal habitats where a high number of species occur in conjunction with human uses. Other papers indicate how telemetric or acoustic data could be used to find new conflicts and compatibilities between megafauna and dynamic human activities such as shipping or seismic exploration (Table 4). As for fishing grounds, even without relevant stakeholder participation and the sharing of information, active fishing grounds can be detected using different combinations of vessel tracking systems with satellite-derived data (Table 6). This type of area-use detection would allow planning for displacement effects if needed, for example, when fishing grounds overlap with planned offshore windfarms (Janβen et al., 2018).

When data gaps occur, planners might need new specific data to cover the gaps. In some countries, like Germany and Spain, the approach is to assemble and work with available data. This usually means using data created for purposes other than MSP, thus working along with data

Table 7
Sources using geospatial technologies to monitor proposed indicators or targets.

	Use	Technology type	Example	References	Added use
Monitoring	*Goodness of fit- Delimitation of conservation areas*	Telemetry	Are MPAs' effectively located/fitting for highly mobile fauna	(Daley et al., 2015; Lea et al., 2016; Paiva et al., 2015; Snape et al., 2018)	Baseline data gathering and DOM
		Passive acoustic	Comparing inside and outside conservation areas	(Bertucci et al., 2016)	
			Assessing fish stock abundance: species identification	(Allken et al., 2019)	
			Spatiotemporal distribution of marine mammals	(Davis et al., 2017)	
	Monitoring species of interest and conservation management assessment	Passive acoustics	Comparison of habitats to themselves over time or comparison to other habitats	(Akamatsu et al., 2018; Borker et al., 2020; Carriço et al., 2020; Elise et al., 2019)	
	Habitat monitoring: Environmental monitoring including anthropogenic effects	Passive acoustics + AIS	Impact of cruise ships in marine mammal sanctuaries	(Roca & Van Opzeeland, 2020)	Baseline data gathering
		AIS/VMS	Risk from vessels for marine mammals	(Coomber et al., 2016)	
		EO satellites	Change in seagrass coverage	(Traganos & Reinartz, 2018a, 2018b)	Baseline data gathering
			Detecting reef areas more susceptible to bleaching	(Genevier et al., 2019)	Baseline data gathering
		Active acoustic surveys (sonar)	Change in benthic coverage	(Heinrich et al., 2017; Sonoki et al., 2016)	
			Seabed alterations	(Heinrich et al., 2017)	
		EO satellites	Harmful algal blooms	(Gokul et al., 2019; Smith and Bernard, 2020; Ye et al., 2019; Zhao et al., 2016)	Baseline data gathering
Monitoring	*Mitigation*	Passive acoustics	Anthropogenic origin noise	(Estabrook et al., 2016; Folegot et al., 2015)	Baseline data gathering
			Risk mitigation impacts of seismic surveys on marine mammals	(Abadi et al., 2017; Banda and Blondel, 2016)	Baseline data gathering
			Monitoring endangered species and habitat management	(Jaramillo-Legorreta et al., 2017; Smith et al., 2020)	Baseline data gathering
			Effectiveness of bycatch mitigation measures	(Hahlbeck et al., 2017; Omeyer et al., 2020)	Baseline data gathering
		Telemetry	Fisheries mitigation: Using temporal restrictions	(Francis et al., 2015)	Baseline data gathering and DOM
			Fisheries effects on sea birds, sharks	(Byrne et al., 2017; Collet et al., 2015; Sommerfeld et al., 2016; Waugh et al., 2016)	Baseline data gathering and DOM

gaps and creating strategic plans, providing guidance about the collection of specific data at a later time (BSH, 2021; "Maritime Space Management Plans", 2020; UNESCO-IOC/European Commission, 2021). Others, namely the Massachusetts Ocean Management Plan delegate resources for collecting specific missing data using various suitable GTs (*2021 Massachusetts Ocean Management Plan - Volume 2 - Baseline Assessment and Science Framework, 2021*). The new UNESCO MSPglobal guide (UNESCO-IOC/European Commission, 2021) states that planners, policy and decision-makers should have a clear view of what type of MSP is developed since it will affect plan development including the set objectives and indicators. Therefore, if the planning system in the country promotes strategic plans and practitioners are satisfied with the data available along with the data gaps, they can go ahead with a more indicative plan (lacking direct requirements); yet if a very detailed planning is required, it is clear that GTs are efficient for timely and precise data gathering for plan development, and support measurable, comparable, scientific, plan indicator monitoring (UNAIDS, n.d.).

Geospatial technologies gather MSP-related data which also includes the third and fourth dimensions (depth and time). Thus, potentially, effective data gathering technologies allow for more spatiotemporal change-sensitive plans to be developed by enabling the refinement of temporal and spatial scale of managed areas even within the plan's timespan. Today, MSP struggles even to include the depth element (third dimension) and plans are mostly in 2D (Levin et al., 2018; Wahle et al., 2020). The temporal aspect (fourth dimension) which could lead to dynamic ocean planning and management is even rarer to encounter in marine plans (Gissi et al., 2018). Dynamic ocean management has been suggested years ago (Dunn et al., 2016; Hazen et al., 2018; Hobday, Maxwell, Forgie and McDonald, 2013; Lewison et al., 2015; Maxwell et al., 2015) and is most similarly applied by fisheries and shipping management (Hobday, Hartog, Spillman and Alves, 2011; Hobday, Hartog, Timmiss and Fielding, 2010; Lewison et al., 2015; Lomonico et al., 2021; Silber et al., 2014). Flexible management measures applied by these sectors offer ways for lowering bycatch and unwanted man-animal interaction (Hazen et al., 2017; McInnes et al., 2019; Siders et al., 2016; White et al., 2019). Introducing spatiotemporal change aspects into marine plans (i.e., flexible management measures) will require robust timely data to rely on, such as the data GTs offer (Tables 5 and 6). Some of the technologies presented support dynamic management with long- and short-term spatial-temporal measures, meaning more potential compatibilities between spatial needs. For example, traffic lanes that are intensely used could have negative environmental effects (noise, oil spill), yet there are serious economic and ecological costs and effects also to rerouting (fuel costs, new habitat disruption) (Conflict fiche 4: Maritime transport and area-based marine conservation, 2019). Deciding to remain with existing traffic lanes that overlap with whale population require speed reduction zones to avoid ship strikes. Depending on whale presence and density, the slow down zone may be changed seasonally or in other areas a real-time detection and warning to vessels might be more suitable. This is because it causes less delay to the shipping industry and can achieve a balance between economic costs and whale conservation (Lewison et al., 2015; Hazen et al., 2017; Reimer et al., 2016). Furthermore, incorporating more spatiotemporal-explicit data in MSP might also help strengthen the link between fisheries management and MSP (Janβen et al., 2018). Fisheries ocean-usage change in time and space, including depth; by including these spatiotemporal refinements in MSP some existing conflicts encountered in the fisheries sector between it and other sectors and with conservation needs might be resolved.

Other management needs such as assuring compliance and enforcement of regulations can be enhanced by the use of geospatial technologies, thus implementing MSP strategies. For example, conservation in MPAs could be enhanced by better targeted enforcement based on GT-derived data. The activities presented in the papers (Table 6) use acoustic traps to identify high-risk pelagic areas, algorithms analyzing AIS data that interpret fisheries activities with a higher temporal resolution than VMS, VIIRS satellites detecting nighttime lighting used by fishers, and SAR satellites that show vessels that turn off their AIS to avoid detection.

There are some limitations to GT technologies we can imagine in this context, such as data management issues (Shaowen et al., 2019; Breunig et al., 2020). No doubt that targeted patrols based on GT data analysis can save on resources and discourage noncompliance(Clark and Humphreys, 2020; Rowlands et al., 2019; Thiault et al., 2020) yet, enforcement agencies will need to consider that by implementing too many technological tools, they might be overwhelmed with the amounts of data needing storage and analysis. Investing in data analysis requires more manpower, software and time and may lead to too many noncompliance alerts to handle (Lee et al., 2019; Hsu et al., 2019; Breunig et al., 2020). Each enforcement agency will have to select the type of tool that can address most of their human uses, while still suiting capabilities, resources and prosecution requirements. For instance, the UK introduced a new GT called I-VMS to surveille small scale fishing activities via cellular reception because regular VMS installed on vessels larger than 12 m as required by law covered only 17 percent of the fishing fleet ("Inshore Vessel Monitoring (I-VMS) for under-12m fishing vessels registered in England," 2022; Vaughan, 2017). Australian enforcement agencies operate at very large scales of sea, and prefer preventing violations in real time rather than going out with patrol to try and catch the violators in the act (Read et al., 2019). Yet if prosecution requires catching violators in-the-act, a predictive policing strategy, analyzing past violation data to target high risk areas with patrols might be more suited (Cimino et al., 2019; Clark and Humphreys, 2020; "Predictive Analytics to Forecast Illegal Fishing Risk in Mexico," 2020).

Monitoring of pelagic and benthic habitat change could be enhanced using earth observation satellites or acoustics. Earth observation satellites can detect changes in habitats such as seagrass coverage and density, and soundscape acoustics allow for a quick estimate of change in habitat health, biodiversity abundance and richness, and anthropogenic pressure. The soundscape compares between different areas (e.g., inside and outside MPAs) or over time at the same habitat. Acoustic or satellite-based telemetry can assess change in the goodness-of-fit between mobile marine fauna and designated conservation areas and aid in decisions to adapt management area borders. The GTs presented (Table 7) support efficient monitoring, meaning the technologies exist and require monitoring programs to keep up with developments and plan data gathering and management accordingly.

Data management and analysis skills are essential for MSP (Flynn et al., 2020; Stamoulis and Delevaux, 2015). As mentioned previously, the anticipated challenges of using more GT-derived data are storage, analysis, and matching scales and databases (Breunig et al., 2020). Funding for building a database will be required as a part of the basic MSP process as more data is collected and generated (Li and Jay, 2020; UNESCO-IOC/European Commission, 2021). Countries, especially those who might have common interests such as EU countries, nations that are part of an archipelago such as the Eastern Caribbean countries, or share ecosystems such as the Benguela Current Convention countries, could consider developing a common database, which would save time and money for future plan adaptations. This would lead to more data sharing advantages, such as comparing environmental surveys data and fisheries data more accurately and would advance transboundary cooperation (Li and Jay, 2020).

Regarding MSP as a policy tool (UNESCO-IOC/European Commission, 2021) and the GT and their derived data as "science", the lack of communication between scientists and policymakers (i.e., the science-policy gap) is demonstrated here, highlighting the importance and need for this type of research. Our evidence-based literature review highlights that out of the 652 records screened for titles and abstracts, about half mentioned management, conservation, or monitoring ($n = 349$, 323 and 214 records, respectively), yet planning was noted only in 170 records suggesting a lack of desired affinity between technology use and planning. We have a few assumptions about why marine spatial planners and operational marine managers might not be using the best available technology. Some might not be aware of all GT-derived data available to them; others may consider them unaffordable or inaccessible in their country. Regulations may be too slow to keep up with the newest technologies, or entities owning the data may be unwilling to share it. Either way, the science is limited in its support of policy (MacDonald et al., 2016; Rumson et al., 2017; Winterfeldt, 2013), as the gaps summarized in this paper also indicate. Beyond familiarizing practitioners with technologies as we have done here, specific case studies are needed to determine the barriers to enhancing GT use.

Understanding how to optimize the use of GT-derived data is critical for improving MSP and for operationalizing ecosystem-based marine management in particular. Looking into the common challenges in MSP suggests further research should aim at creating enhanced methodologies in greater detail for integrating technologies into the MSP process. Preferably, the role of GTs (data and tools) would be addressed by responsible agencies through their management policies.

CRediT authorship contribution statement

Inbar Schwartz Belkin: Conceptualization, Investigation, Writing - Original Draft.

Michelle E. Portman: Writing - Review & Editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. supplementary data

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