Monitoring elasmobranchs in marine protected areas: A Canadian case study of the Laurentian Channel.

Authored By

Samantha Renshaw

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Abstract

Scientific support for the application of Marine Protected Areas (MPAs) for shark and ray (herein elasmobranchs) conservation varies widely in current literature. Several MPAs around the globe have been created with the purpose of protecting elasmobranch species, however, their suitability and effectiveness are often questionable. Telemetry (electronic tagging) is widely used to better understand shark ecology and behaviour, yet the application of insight gained through these studies for conservation and management, particularly with respect to MPA efficacy, is inconsistent. A systematic literature review was conducted to determine how telemetry has been used to monitor and evaluate MPAs for elasmobranch species. Several aspects of telemetric MPA monitoring were investigated including the nature of the study area, study duration, species, MPA restrictions and methodology. Results of the review are useful to inform the newly designated Laurentian Channel MPA (LCMPA) and its proposed conservation objectives to protect three species of elasmobranch: Porbeagle shark (*Lamna nasus*), Black Dogfish (*Centroscyllium fabricii*) and Smooth Skate (*Malacoraja senta*). Recommendations for an elasmobranch monitoring plan are discussed to inform management of the LCMPA. Carrying out these recommendations will serve to bridge the current gaps in knowledge of these species' movements and distribution and aid elasmobranch species conservation in Canada.

Keywords: Telemetry, elasmobranch, MPAs, monitoring, evaluation, Laurentian Channel

List of Abbreviations

AOI	Area of Interest
CBD	Convention on Biological Diversity
CHUA	Core Habitat Use Area
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Department of Fisheries and Oceans
EBSAs	Ecologically and Biologically Significant Areas
EEZ	Exclusive Economic Zone
ESSCPs	Ecologically and Biologically Significant Species and Community Properties
ESSIM	Eastern Scotian Shelf Integrated Management Area
GBRMP	Great Barrier Reef Marine Park
GOSLIM	Gulf of St. Lawrence Integrated Management Area
IUCN	International Union on the Conservation of Nature
LCMPA	Laurentian Channel Marine Protected Area
LOMA	Large Ocean Management Area
MPA	Marine Protected Area
NAFO	North Atlantic Fisheries Organization
OAP-I	Ocean Action Plan I
OECM	Other Effective Area Based Conservation Measures
PBGB	Placentia Bay-Grand Banks
PNCIMA	Pacific North Coast Integrated Management Area
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PSAT	Pop-up Satellite-Linked Archival Tag
SARA	Species at Risk Act
SPOT	Smart Position and Temperature Transmitting Tags
YOY	Young of Year

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1. Introduction

Elasmobranchs (shark, skate and ray species) are at risk from anthropogenic activities including bycatch, habitat destruction and overfishing, all of which have contributed to shark and ray population declines worldwide (Worm et al., 2013). Marine Protected Areas (MPAs) and Other Effective area-based Conservation Methods (OECMs; in this report the term MPAs includes "marine reserves, sanctuaries, parks, no-take zones or areas, fishery exclusion zones, fishery reserves and closed areas" (MacKeracher, Diedrich, & Simpfendorfer, 2019)) are often implemented as spatial conservation tools to preserve biodiversity, limit environmental degradation and protect vulnerable species, including elasmobranchs, from exploitation (Dureuil et al., 2018). Global MPA coverage within territorial waters has increased from less than 1% in 1982, to nearly 13% by mid-2018 (Jantke et al., 2018). This movement is largely driven by the Aichi Target 11 under the Convention of Biological Diversity's (CBD) Strategic Plan that encourages signatories to protect 10% of their ocean space by designating MPAs or OECMs, by 2020 (CBD, 2010). However, while these targets have globally increased both awareness and spatial protection measures, some critics are skeptical about the value of many protected areas when harmful activities are permitted to continue within their boundaries or when the species intended to be protected have large or unknown distributions (Dureuil et al., 2018). These cases are commonly referred to as 'paper parks' and efforts to improve management, evaluation and enforcement of protected areas must increase to avoid inadequate or negative outcomes (Brown et al., 2018).

Increasingly, MPAs have been designed as a tool for elasmobranch conservation and fisheries management, such as the creation of 'Shark Sanctuaries' which in 2017 accounted for more than 3% of the world's ocean (Ward-Paige & Worm, 2017). Sanctuaries are often declared when a country prohibits the catch and trade of elasmobranchs within their exclusive economic zones (EEZ

), with examples including Palau and the Bahamas. Similarly, stand-alone or networks of MPAs have been designated with conservation objectives to protect and facilitate recovery of sharks and rays, but may have varying degrees of allowable activity ranging from multi-use to no-take zones (Bonfil, 1999; Davidson & Dulvy, 2017; MacKeracher et al., 2019). Largely due to uncertainty and lack of data, the evidence showing MPAs help elasmobranch conservation is inconsistent throughout the current literature. “The establishment of very large MPAs and shark sanctuaries has far outpaced research on their ecological effectiveness” (CMA, 2018). Thus, MacKeracher et al., (2019) critically evaluated current perspectives on MPAs for shark and ray conservation. They concluded that MPAs for elasmobranchs were slightly more effective than average protected areas for conservation, but on their own were insufficient. In general, MPAs are thought to work best for the conservation of sedentary or less mobile species, and have been shown to provide recovery benefits for reef fish and coral habitats (McClanahan et al., 2007). While such success stories highlight the benefits of MPAs, it is clear that they are not a silver bullet for fisheries management (Hilborn et al., 2004). In almost all cases, species of concern traverse the boundaries of protected areas, leaving them vulnerable to exploitation outside these zones. This is especially true for many elasmobranchs which exhibit highly mobile lifestyles, occupy large home ranges, and may use the waters of multiple national jurisdictions and the high seas. Thus, to determine the value of a given MPA, studies are needed that investigate the distribution, abundance and site fidelity of species in relation to MPA boundaries and regulations, as species whose ecological space use is closest to the size of the MPA should be afforded the most protection (Palumbi, 2004; Stanley et al., 2015). Understanding species distribution within MPAs is therefore critical to evaluate their success and long-term effectiveness.

For elasmobranchs, telemetry research has helped reveal critical habitats for consideration for protection including pupping grounds, migration corridors, and foraging sites (Hussey et al., 2015). Many telemetry studies have provided evidence supporting MPA designation or motivated the creation of sanctuaries for at-risk species (Cooke et al., 2005; Cooke, 2008; Fraschetti et al., 2005; Espinoza et al., 2011). Understanding the opportunities and limitations of telemetry and other sampling methods is essential to best inform MPA management. While there is currently no established best-practice format for monitoring elasmobranchs in MPAs, existing global research activities on the topic may be useful to advise Canadian research initiatives. Thus, research aimed at improving MPA monitoring using biotelemetry will benefit the management of future and existing protected areas.

At the time of writing, Canada has 14 MPAs designated under the *Oceans Act* and four more National Marine Conservation Areas designated under the *Canada National Marine Conservation Areas Act*. The very recently designated Laurentian Channel Marine Protected

Area (LCMPA) aims to conserve (among other species) three elasmobranchs with differing life history strategies and distributions; Porbeagle shark (*Lamna nasus*), Black Dogfish (*Centroscyllium fabricii*) and Smooth Skate (*Malacoraja senta*). Telemetry and trawling surveys helped inform the designation of the LCMPA, yet large knowledge gaps remain about the basic ecology of these three species and their use of the LCMPA. Trawl surveys can help define the temporal and spatial distribution of species, but they are typically lethal to the animals caught. This is not a recommended sampling method for endangered species. Such questions may be better addressed using telemetry studies. However, the current lack of monitoring infrastructure (i.e., acoustic receiver arrays) within the LCMPA boundaries and a paucity of historic information on species distributions make it difficult to assess the overall effectiveness of species protection at this site (Lewis et al., 2016).

A management plan that will detail comprehensive regulations and an approach to monitoring and enforcement for the LCMPA is still in development (DFO, 2019). Current management of the LCMPA may be best informed from the application of an extended telemetry research initiative focused within the MPA, and future studies would build on this baseline knowledge to document shifts in species distribution due to changing ocean conditions (Lewis et al., 2016). Implementing the best possible monitoring strategies including comparable, long-term and fine-scale data collection, greatly assists with the development of an optimum adaptive management plan.

The purpose of this study is to review how telemetry has been applied to evaluate MPAs for elasmobranch species globally in order to identify the ways in which telemetry-based monitoring efforts can be best implemented for the LCMPA. Specifically, I am seeking to answer: 1) what telemetry methods are used to monitor and evaluate elasmobranchs in MPAs? and of these methods, 2) which (if any) are used to track species similar to those within the LCMPA? To answer these questions, I have conducted a literature review of studies that tracked elasmobranchs within MPAs using electronic telemetry, extracted the lessons learned, and have used these lessons to provide recommendations for the LCMPA research and monitoring program. A species profile and current knowledge overview of the Laurentian Channel area was completed to better understand the creation of the LCMPA and identify the research gaps that will need to be filled as it's MPA's management plan is developed.

2. Biotelemetry

Telemetry refers to the transmission of information from one electronic instrument to another. Biotelemetry more specifically, applies to the use of telemetric technology to monitor animals and includes a suite of tools (electronic tags, receivers, analytical methods) that can help identify patterns in animals' 4D spatial movements. There are several types of telemetry which a researcher may choose and depending on the purpose of tracking the animal, these include acoustic and satellite telemetry, biologgers, and combined approaches. A good overview of these methods is provided by (Cooke et al., 2012), but in the literature reviewed for this study the following telemetry technologies were used with chondrichthyans:

2.1 Acoustic telemetry

Acoustic telemetry involves the allocation of transmitting devices (tags) to individual animals that send out a series of sound waves (or "pings") to be detected by receiving devices (Cooke et al., 2012). Acoustic receivers then record the information when the tags are within range. These ranges can exceed several hundred meters depending on tag power and environmental conditions. Tags emit unique identification codes that allow researchers to pin-point individuals and follow their movements. There are several ways acoustic telemetry information can be gathered. Active tracking requires continuous "listening" by researchers that follow the animals to detect acoustic signals and identify individuals using a hydrophone. These studies are usually undertaken by boat but can be performed on foot in some coastal environments. Passive acoustic tracking involves the deployment of acoustic receivers underwater that continuously listen for tags and store transmitted information (i.e., date, time, ID code) until it is offloaded. Receivers are often arranged strategically in arrays which require regular maintenance and collection for data retrieval. Acoustic tags can be implanted into an animal's body cavity with a small surgical procedure or be affixed on the outside of the body on a stalk anchored into the musculature of the animal.

2.2 Satellite Tracking

Using a similar attachment process to externally mounted acoustic tags, satellite transmitters are attached to an animal and send signals periodically to researchers via orbiting satellites

(Cooke et al., 2012). This information includes estimates of the location of where the animals was when the signal was sent (Hammerschlag et al., 2011). Location estimates are made via triangulation once a satellite receives two or more consecutive signals. Better and more accurate satellite technologies continue to be developed, improving tracking capabilities and in some cases providing near real-time data. Smart position or temperature transmitting (SPOT) tags provide high resolution estimates of an animal's location. These tags have been used almost exclusively as the satellite telemetry used for shark tracking (Hammerschlag et al., 2011).

When information is recorded and stored in animal tags, or archival loggers, this is called biologging (Cooke et al., 2012). Similar to biotelemetry, biologgers allow animal's movements to be tracked and evaluated by storing information such as temperature, depth, and positions as determined from ambient light (light-based geolocation). Data is collected from these devices when (or if) they are recovered. These tags are often used in marine environments and some models are programmed to fall off the animal after a set time.

In many instances, a combination of data collection methods is used, and these devices are deemed hybrid technologies; pop-up satellite archival tags (PSAT) transmit stored data to satellites when the tags release from their host and float to the surface (Cooke et al., 2012). For the scope of this study, any telemetry or logging device is considered a satellite technology if it links to satellites. Although conventional identification and archival tag-recovery studies were not included here as they were beyond the scope of this investigation, a good overview can be found in (Latour, n.d.).

3. Methods

A systematic literature review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Figure. 1). A literature search was conducted using a combination of search terms including 'marine protected areas OR marine reserves' AND 'telemetry' AND 'elasmobranch* OR skate* OR ray* OR shark*' AND "monitor* OR evaluation" to identify papers that contained these within titles, keywords, or abstracts. An initial search of the online databases Web of Science and Science Direct yielded 40 and 3 results respectively. Once duplicates from these results were removed, the search garnered 41 unique results. An expanded search to include entire articles using the above terms was performed on Science Direct to reveal an additional 226 papers. Only papers that met the criteria for terms within title, keywords or abstracts were extracted from this search. Other relevant sources were found within works cited from the previously identified papers, totaling an additional 30 records. From each study, the following information was recorded: (1) study location, (2) habitat type (3) study purpose, (4) species monitored/life history strategies (5) telemetry methods/technology applied, (6) study duration, (7) total area of study, (9) protected area designation (No-take, Species Specific Restrictions, Multiple Use, Fishing Restrictions, No-go, or No-designation), (10) limitations, and (11) conclusions/outcomes. The information recorded from these studies was then sorted and analyzed to help draw more general conclusions about the application of telemetry for MPA monitoring as outlined below. When appropriate, statistical analysis was conducted using t-tests and deemed significant at a p-value of <0.05.

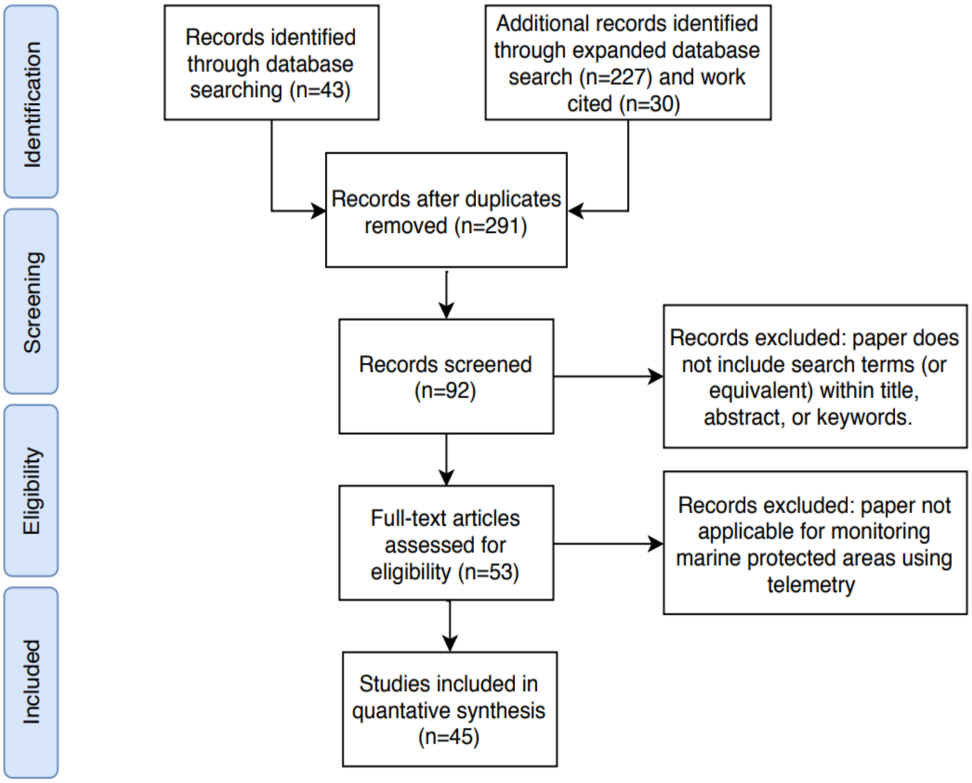

Figure 1. PRISMA framework used to guide telemetry literature search.

3.1 Location and Habitat

Study locations were mapped worldwide and grouped into seven ocean regions (North Atlantic, South Atlantic, North Pacific, South Pacific, Indian, Southern and Arctic Ocean).

3.2 Purpose

The purpose of each study was identified within the introduction section of the papers and recorded. Purposes were grouped using commonly stated objectives to determine general trends. Given the criteria for selecting review papers (Figure 1), all studies stated an overall purpose of evaluating marine protected areas or OECMs, thus, this was not recorded as a purpose for studies individually. If the purpose was unclear after reading the introduction, a simple word search for common monitoring attributes was conducted and considered to have been a purpose of the study if the monitoring attribute appeared in the methods and/or results section of that paper.

3.3 Species and Life History

Each species and their corresponding life history strategies were recorded for each study. The status of each species as assigned by the International Union for Conservation of Nature (IUCN) Red List was recorded for each species. Species were assigned to a life history category in accordance with those outlined in Bonfil, (1999). These groups include: Bottom dwelling, Deep-water, Gigantic/planktivorous, Migratory (neretic), Non-migratory (neretic), and Oceanic. Bonfil, (1999) provides examples of species belonging to each category and species were given these designations in this review. For species not previously classified, their biological characteristics were evaluated and matched to the defined groups based on their exhibiting similar behaviour or belonging to the same genus as other members of the groups. These assignments are based on the best available information regarding each species.

3.4 Telemetry Technology and Methodology

The telemetry technology and methodology used in each study was recorded. First studies were determined as having used satellite-linked, acoustic telemetry, or a combination of both and noted accordingly. Secondly, the type of technology was noted, including the arrangement of acoustic receivers when applicable. Common categorizations of acoustic receiver deployments were used to group the studies. These included curtains, hotspots, networks, outside the MPA, within the MPA, on the MPA perimeter, and other. The term curtains included studies that used gates, curtains, choke points or their equivalents within their array design. Studies identified as using hotspots put their receivers in locations where elasmobranchs were known to occur (i.e., known aggregation or feeding sites). Those included in the network grouping were studies whose area was encompassed in a larger array of receivers and used either part of all of the receivers in the network for their analysis (these often covered an area much larger than the study site). The categories outside and within the MPA meant studies had an assortment of receivers outside or within their MPA. Perimeter arrays were positioned at the boundary line of the protected area. Studies included in the other category utilized an alternative method than those described above, or were not described within the study.

3.5 Duration

The duration of each study was recorded as the number of months during which data was collected. It was then noted which studies took place for equal to or less than one year (12 months) to draw conclusions about seasonality investigations.

3.6 MPA Size

The total area of each MPA was recorded from information either offered within the study itself or through online investigation of the site. Using the size classes outlined in Stanley et al. (2015) as a guide, the size of each MPA was then sorted into a corresponding category based on total area: Mini (0-0.1 km^2), XX-Small (0.1-1 km^2), X-Small (1 -10 km^2), Small (10 – 100 km^2), Medium (100 – 1000 km^2), Large (1000 - 10,000 km^2), X-Large (10,000 - 100,000 km^2), XX-Large (100,000 - 1,000,000 km^2), Mega (1,000,000 - 10,000,000 km^2). Using the IUCN World Database on Protected Areas (marine), reported protected areas with a definable size (an area greater than 0 km^2), were grouped per the above size classes.

3.7 Area Designation

The restrictions imposed for each protected area were recorded and simplified. Four of the studies monitored MPAs that had not been officially designated yet. However, these areas were classified as MPAs in their respective studies. In all cases elasmobranchs were monitored in these areas to determine potential MPA effectiveness prior to implementation. Similarly, some studies reported on the effectiveness of ‘Shark Santuaries’, inclusive of a country’s EEZ, and were considered for this review if they included protection measures for at least one species of elasmobranchs. These areas were included as they used relevant methodology and techniques for review purposes. All MPAs had zones reflecting at least one, if not several of the following: No-take, Species Specific Restrictions, Multiple Use, Fishing Restrictions, No-go, or No-designation.

3.8 Outcomes and Limitations

The final outcomes or conclusions from each study were recorded and summarized. In each study it was also noted whether the research was able to provide estimates of MPA effectiveness. These studies were then categorized as having determined if the MPA was successful for providing protection to the species it monitored: (A) yes, the MPA offered suitable or sufficient protection, (B) yes*, the MPA offers some protection (i.e., some decrease in fishing pressure or anthropogenic risk or protection to some life history stages but not others), (C) no, the MPA provided inadequate, limited, or no protection. General limitations related to the methodology or conclusions of each study were recorded and discussed generally on a case-wise basis within the discussion.

4. Results

The search for primary literature that used telemetry technology to track elasmobranchs within MPAs yielded 45 studies that monitored a total of 42 MPAs. In general, there was an increase in the number of studies that have used telemetry to monitor elasmobranchs within MPAs over the last 14 years; the earliest being published in 2005 (Figure 2). The following sections highlight the relevant information extracted from these studies.

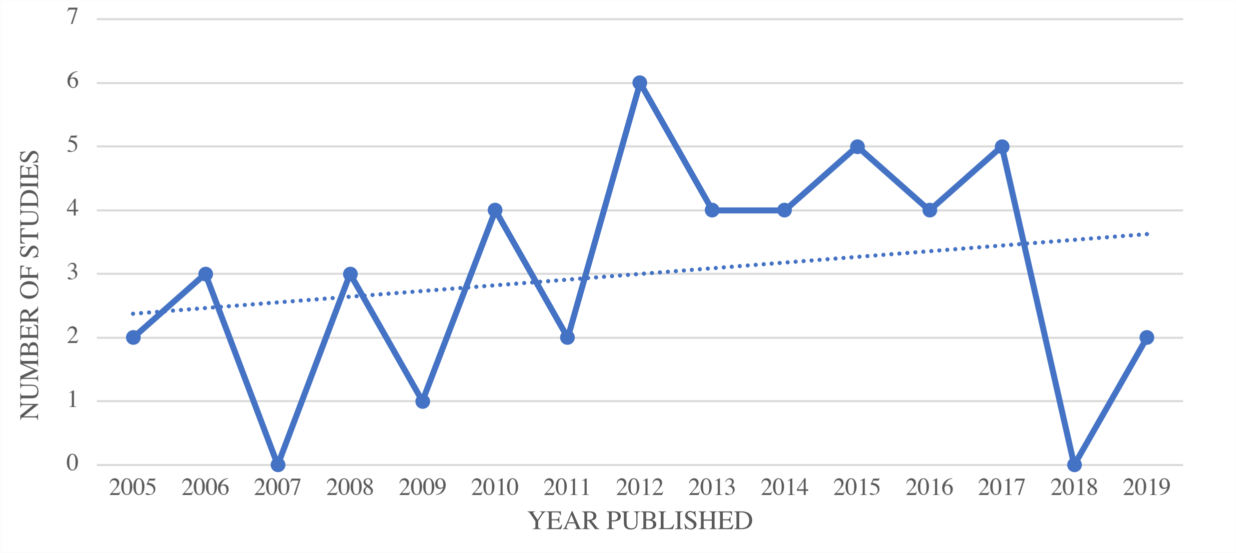

Figure 2. The number of studies per year that monitored elasmobranchs in MPAs using telemetry technology published in each year. Note this study was completed before the end of 2019, which may result in an incomplete count of studies for that year, changing the overall trajectory.

4.1 Location and Habitat

Most studies occurred in the Pacific Ocean (in entirety) (n=19; Figure 3; Figure 4). By ocean region, the Indian Ocean contained the most study locations (n=12), followed by the North Atlantic and Pacific (n=10 each). No examples were found in the Arctic or Southern Oceans. One study took place in two oceans, choosing comparative locations in the Bahamas and Fiji (Brunnschweiler et al., 2010). In some cases, an MPA was monitored in more than one study. Eight additional MPAs were monitored throughout more than one study, bringing the total to 10 examples of replicated monitoring.

Reef systems were the most common habitat monitored and studies took place almost exclusively along the continental shelf. All MPAs within archipelagic regions or around seamounts were monitored using acoustic telemetry or mixed methods, never satellite telemetry alone. Similarly, nearly all MPAs that covered reef habitat were monitored using acoustic telemetry. Two studies occurred in open waters away from the coast, and both used satellite telemetry (Rodríguez-Cabello & Sánchez, 2014; Rodríguez- Cabello et al., 2016).

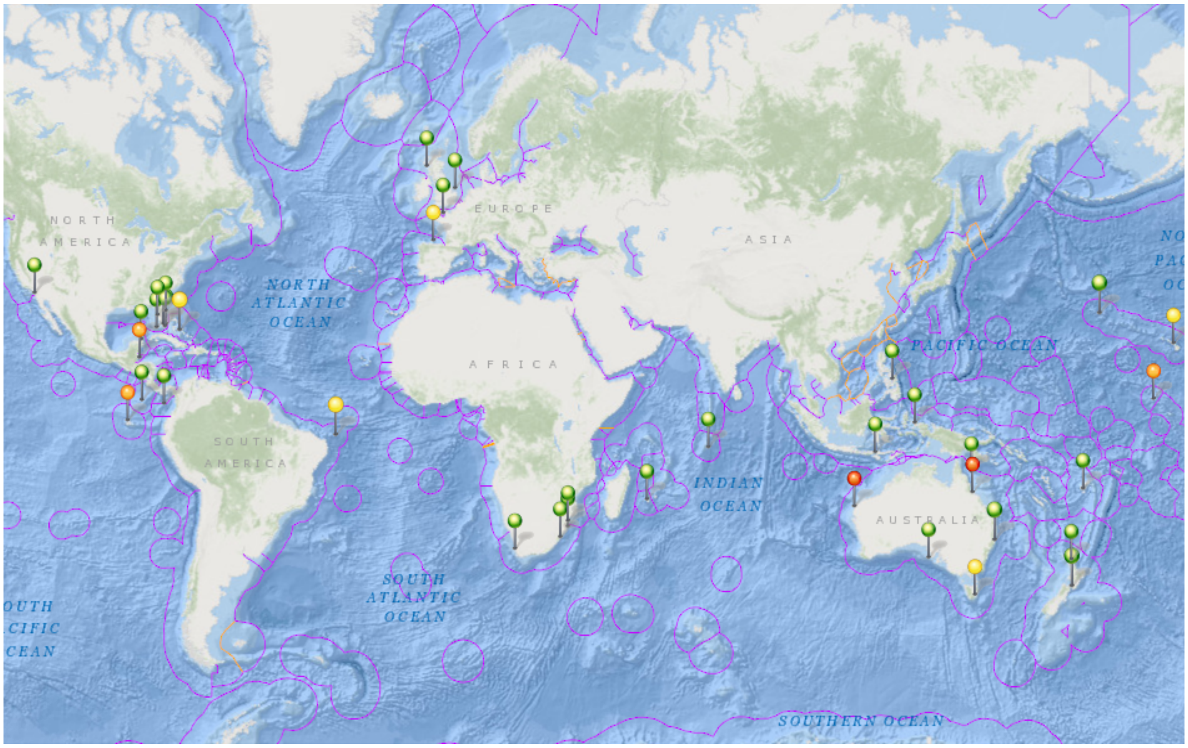

Figure 3. Map of locations where protected areas have been monitored for elasmobranch species using telemetry studies. Pin colours indicate the number of studies that have monitored these areas; green = 1 study, yellow = 2, orange = 3, red =4. Purple lines show the boundary of respective countries exclusive economic zones.

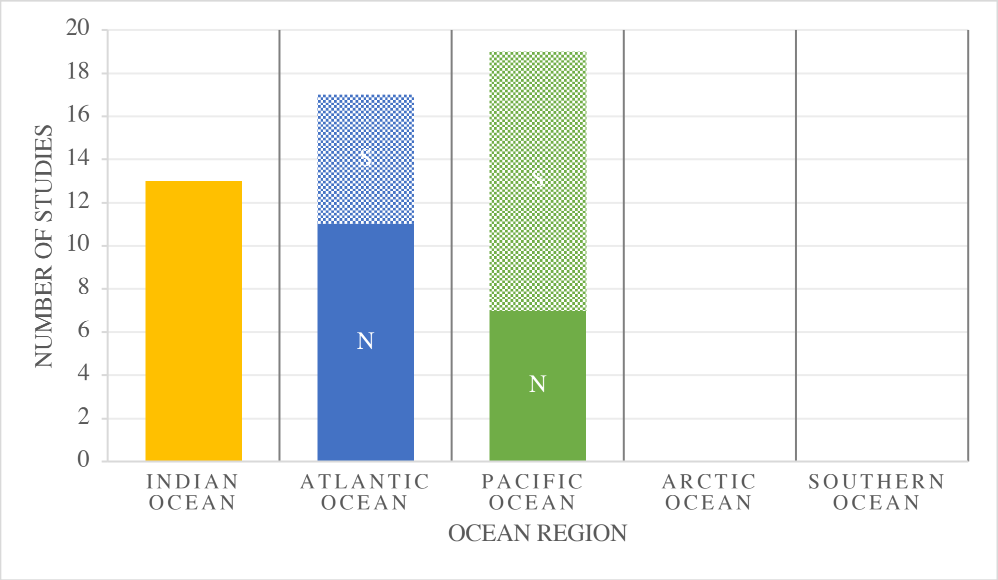

Figure 4. Number of studies sites located within each ocean region. There are seven regions in total, two within the Atlantic and Pacific each, shown as solid or cross-hatched sections within each column representing North (N) and South (S) regions respectively.

4.2 Purposes

Common purposes outlined throughout the studies were related to investigating movement patterns, diel migrations, site fidelity and residency, sexual segregation, and habitat connectivity. Studies were classified as investigating movement patterns if they indicated that vertical or horizontal movements, migrations, spatial use or some other equivalent were measured. Nearly all studies (~98%) examined the movement patterns of species using telemetry in relation to protected areas (Figure 5). This equated to 44 of the 45 studies, with the one exception using telemetry to provide mortality estimates only (Knip et al., 2012a). Site fidelity and residency were often linked and were recorded as one category. This category included studies that recorded "time spent within the MPA' or evaluated the Core Habitat Use Area (CHUA). Site fidelity or residency was examined in 82% of studies (n=37). Less than half of the studies investigated seasonality, diel patterns, habitat connectivity, or sexual segregation (38%, 22%, 20%, and 4% respectively). Sexual segregation was considered investigated if a study performed a movement analysis based on sex of the species and required that the study had specified this as an objective within their methods. Many papers recorded the sex of the tagged animals but did not consider it as a variable to explain movement patterns. Detailed accounts of study objectives are provided in the Appendix. Acoustic and satellite telemetry were used to investigate all identified study purposes and neither methodology was favoured over the other to investigate a given parameter. However, every study that used both acoustic and satellite telemetry (n=4) monitored movement patterns, seasonality and site fidelity.

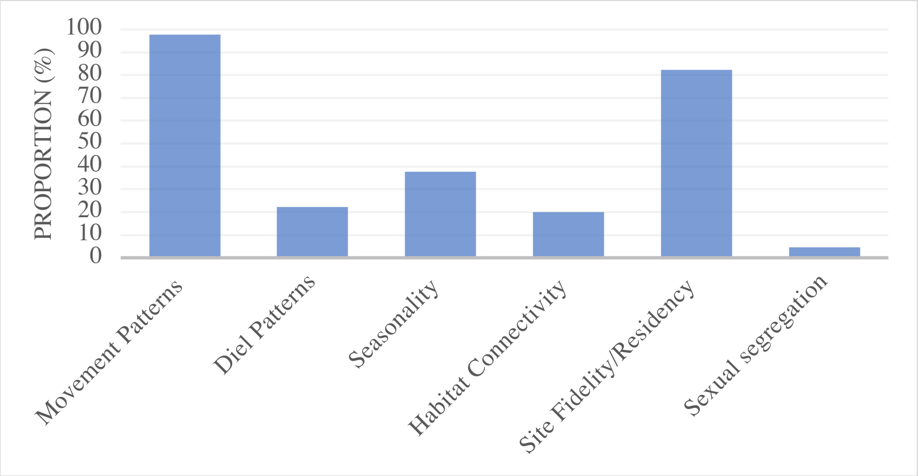

Figure 5. Proportion of studies that stated each measurement as the purpose for their investigation.

4.3 Species and Behaviour

A total of 36 species were studied. The species most frequently studied was the grey reef shark (*Carcharhinus amblyrhynchos*), tagged in seven studies (Barnett et al., 2012; Carlisle et al., 2019; Espinoza et al., 2015a; Filous et al., 2017; Speed et al., 2012; Speed et al., 2016; White et al., 2017; Table 1). Non-migratory species made up the largest proportion of life histories examined, accounting for half of species across all studies (50%; Figure 6.). The Giant guitarfish (*Glaucostegus typus)* was the only species monitored with a critically endangered status. Five were tagged in the single study which investigated this species (Cerutti-Pereyra et al., 2014). Four species that were tracked were designated as data deficient, and one was not evaluated by the IUCN. Three of the species studied are listed as Endangered and each falling under different behaviour categories. Five species were categorized as Least concern and ten as Near Threatened. Most species fell into the Vulnerable category (n=11).

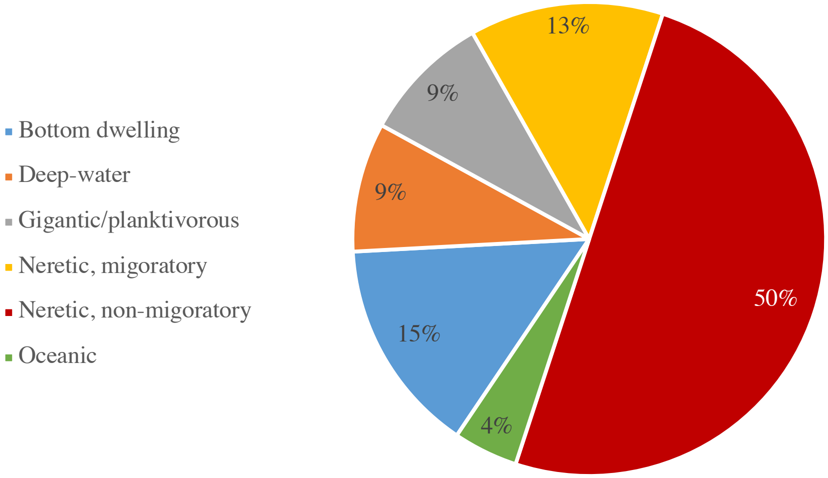

Figure 6. Proportion of studies that monitored species with each behaviour category.

Table 1. Species' common and Latin names sorted by behaviour category, and giving IUCN Red List status, and the number of studies in which a given species was monitored.

Behaviour	Species	IUCN Listing	# Studies
Bottom dwelling	Giant Guitarfish (*Glaucostegus typus*)	Critically Endangered	1
	Porcupine ray (*Urogymnus asperrims*)	Vulnerable	1
	Reticulate or Honeycomb ray (*Himantura uarnak*)	Vulnerable	1
	Blonde ray (*Raja brachyura*)	Near Threatened	1
	Small-eyed skate (*Raja microocellata*)	Near Threatened	1
	Short-tailed stingray (*Dasyatis brevicaudata*)	Least Concern	1
	Wobbegong shark (*Orectolobus halei*)	Least Concern	1
	Broad cowtail ray (*Pastinachus atrus*)	Least Concern	1
	Nurse shark (*Ginglymostoma cirratum*)	Data Deficient	2
Deep-water	Leafscale gulper sharks (*Centrophorus squamosus*)	Vulnerable	2
	Smooth/Spotted dogfish, aka Rig (*Mustelus lenticalatus*)	Least Concern	2
	Broadnose sevengill shark (*Notorynchus cepedianus*)	Data Deficient	1
	Southern Dogfish (*Centrophorus zeehaani*)	Not Evaluated	1
Gigantic/planktivorous	Basking shark (*Cetorhinus maximus*)	Endangered	2
	Giant Manta (*Manta birostris*)	Vulnerable	2
	Reef manta (*Mobula alfredi*)	Vulnerable	2
Migratory (neretic)	Great hammerhead (*Sphyrna mokarran*)	Endangered	1
	Bull shark (*Carcharhinus leucas*)	Near Threatened	4
	Galapagos sharks (*Carcharhinus galapagensis*)	Near Threatened	1
	Tiger shark (*Galeocerdo cuvier*)	Near Threatened	3
Non-migratory (neretic)	Scalloped hammerhead (*Sphyrna lewini*)	Endangered	3
	School/Tope shark (*Galeorhinus galeus*)	Vulnerable	1
	Sicklefin lemon shark (*Negaprion acutidens*).	Vulnerable	2
	Silvertip shark (*Carcharhinus albimarginatus*)	Vulnerable	3
	Black tip reef shark (*Carcharhinus melanopterus*)	Near Threatened	6
	Caribbean reef shark (*Carcharhinus perezi*)	Near Threatened	3
	Grey Reef shark (*Carcharhinus amblyrhunchos*)	Near Threatened	7

	Spottail shark (*Carcharhinus sorrah*)	Near Threatened	2
	Whitetip Reef shark (*Triaenodon obesus*)	Near Threatened	3
	Leopard shark (*Triakis semifasciata*)	Least Concern	1
	Nervous shark (*Carcharhinus cautus*)	Data Deficient	1
	Pigeye shark (*Carcharhinus amboinensis*)	Data Deficient	2
Oceanic	Oceanic whitetip sharks (*Carcharhinus longimanus)*	Vulnerable	1
	Pelagic thresher shark (*Alopias pelagicus*)	Vulnerable	1
	Silky Sharks (*Carcharhinus falciformi*s)	Vulnerable	1

4.4 Telemetry Technology and Methodology

The most common telemetry technology used to monitor elasmobranchs in MPAs was acoustic tags, used in 34 of the studies. Conversely, 15 studies used satellite transmitters. Four studies used a combination of acoustic and satellite technology. A total of ten studies used mixed methods, including non-telemetric approaches. Specific methodologies such as the configuration of acoustic receiver networks varied among studies. Some studies exhibited multiple array patterns and were included in every category they aligned with. The total number of studies that used more than one acoustic arrangement was eleven, representing 32% of the acoustic telemetry studies examined. Most studies arranged acoustic receivers within the MPAs (n=16), followed by placing receivers in known hotspots (n=10; Figure 7). Few studies constructed networks of receivers (n=2), arranged receivers outside MPAs (n=2), or around the perimeter (n=3). On average, studies that used hotspot receiver placements used fewer acoustic receivers in their arrays compared to the other arrangement categories. Curtain and network arrangement categories used the most receivers on average.

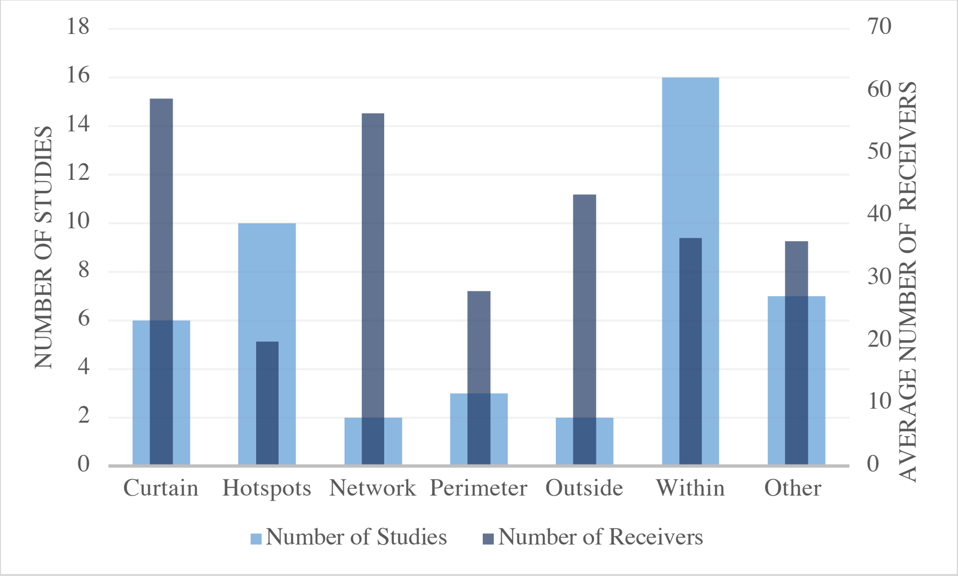

Figure 7. Number of studies that arranged receivers per each arrangement category (Blue, primary axis; note that studies using more than one arrangement were included in both categories) and the average number of receivers used to construct each arrangement category (Grey, secondary axis).

Three types of satellite tags were used; pop-up satellite archival tags (PSAT), smart-position or temperature satellite tags (SPOT), and SPLASH tags (a combined archival and satellite-linked transmitter tag). Two studies deployed both PSAT and SPOT tags on animals throughout their investigations (Doherty et al., 2017; Meyer et al., 2010). In fact, Meyer et al., (2010) deployed acoustic, PSAT, and SPOT tags simultaneously on eight individuals (from two species). On average, the size of MPAs monitored using satellite and acoustic technology was 349, 041 km^2 (n=20) and 84,588 km^2 (n=36) respectively. Thus, satellite technology was used to monitor larger MPAs significantly more than acoustic technology (p=0.05). Yet, the number of individual animals tagged in the studies was significantly larger for acoustic telemetry studies compared to satellite studies, averaging 26 (n=55) and 13 (n=22) respectively (p=0.0012).

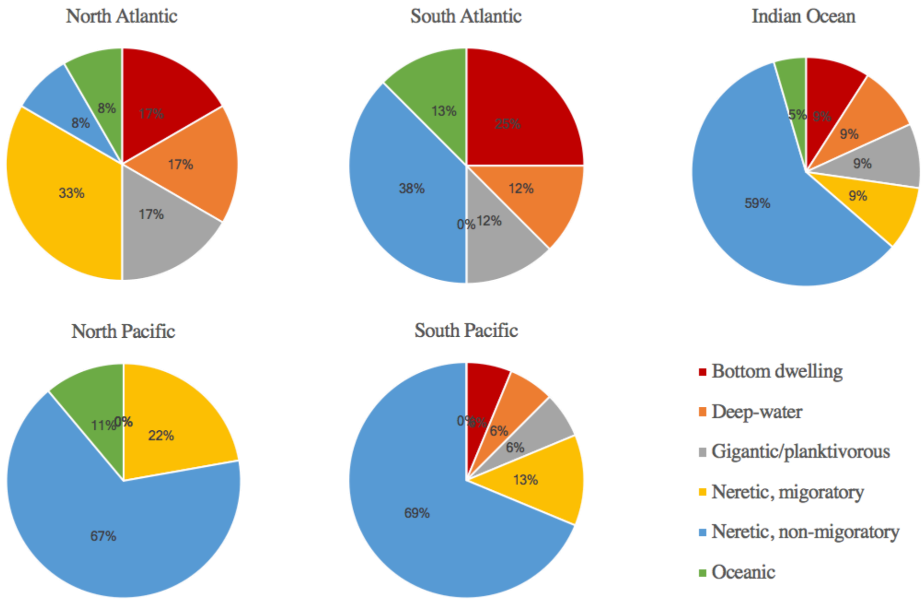

Figure 8. Proportions of species belonging within each life history category studied in each ocean region.

The technology used to monitor elasmobranchs within MPAs varied with species and their life history strategies. For bottom dwelling, deep-water and non-migratory species, acoustic telemetry was the most utilized method of monitoring; 91%, 57% and 91% respectively by proportion of total studies performed on these groups. However, for the remaining three categories, Gigantic/planktonic and migratory and oceanic, satellite telemetry was used for a greater proportion of studies (67% each). Proportions of species behaviours monitored within each ocean region varied (Figure 8). Non-migratory species made up the majority of species monitored in all except the North Atlantic Ocean.

4.5 Duration

The longest study took place over 4 years and the shortest lasted just two months (see Appendix for details). In total, eight studies were performed for less than one year. Most studies (n=37, 82%) were performed for equal to or more than one year. Acoustic studies were significantly longer than satellite studies with an average length of 23.4 (n=30) and 11.9 (n=11) months respectively (p=0.006). Studies that used both acoustic and satellite technology had a longer average duration than studies using acoustic or satellite telemetry studies alone (27 , n=4), yet statistical comparisons were insignificant (p >0.05) among groups. There was no significant relationship between study area and study duration (p >0.05). Of the studies that measured seasonality (n=17), only one was performed for a duration of less than a year (Daley et al., 2015). This study, however, was performed for 90 day periods in 3 different years.

4.6 MPA Size

Large MPAs were the most frequently monitored, while no MPAs smaller than 0.1km^2 were monitored (Figure 9). MPA size varied with the smallest and largest monitored area sizes being 0.31 and 1,621,632 km^2 respectfully (Figure 10). Graham et al. (2016) defined the entirety of the United States EEZ as one of their locations for monitoring elasmobranchs. The US EEZ covers an area of 11,351,000 km^2, including territories. Their study, however, took place exclusively on the Atlantic coast and within the Gulf of Mexico, covering 1,621,632 km2 of the US EEZ (VLIZ, 2019).

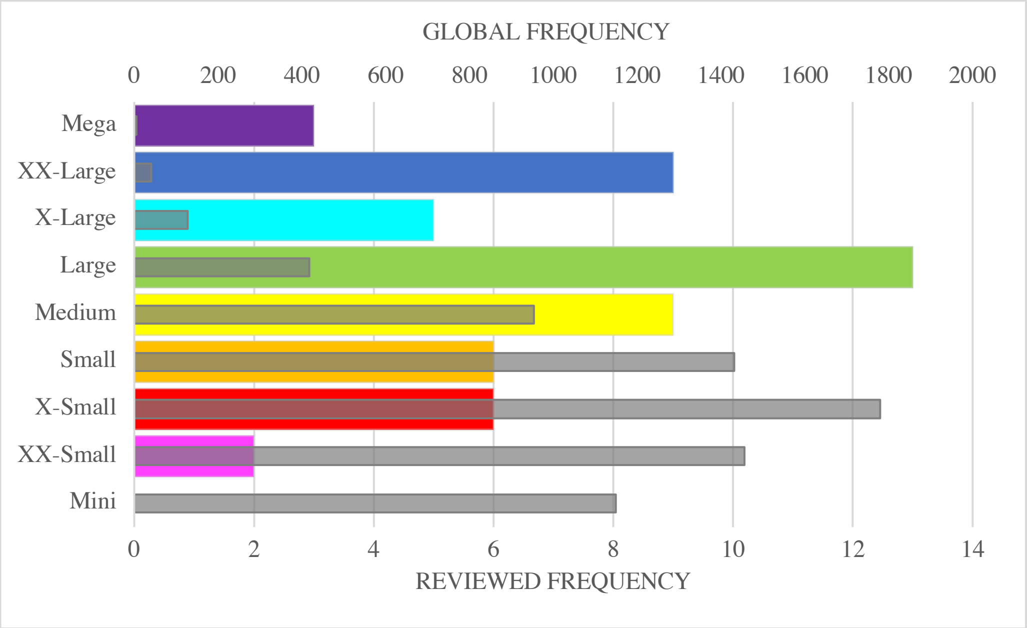

Figure 9. Number of MPAs in each size category (grey bars, top x axis, from the IUCN World Database on Protected Areas (2019). Note that the frequency of Mega MPAs is 6 which is not visible on the figure given the scale on the axis) with numbers of MPAs in different size categories (bottom x axis) projected in colour. Mini (0-0.1 km^2, none in this review), XX-Small (pink; 0.1-1 km^2), X-Small (red; 1 -10 km^2), Small (orange; 10 – 100 km^2), Medium (yellow; 100 – 1000 km^2), Large (green; 1000 - 10,000 km^2), X-Large (cyan; 10,000 - 100,000 km^2), XX-Large (blue; 100,000 - 1,000,000 km^2), Mega (purple; 1,000,000 - 10,000,000 km^2). The number of MPAs in the IUCN

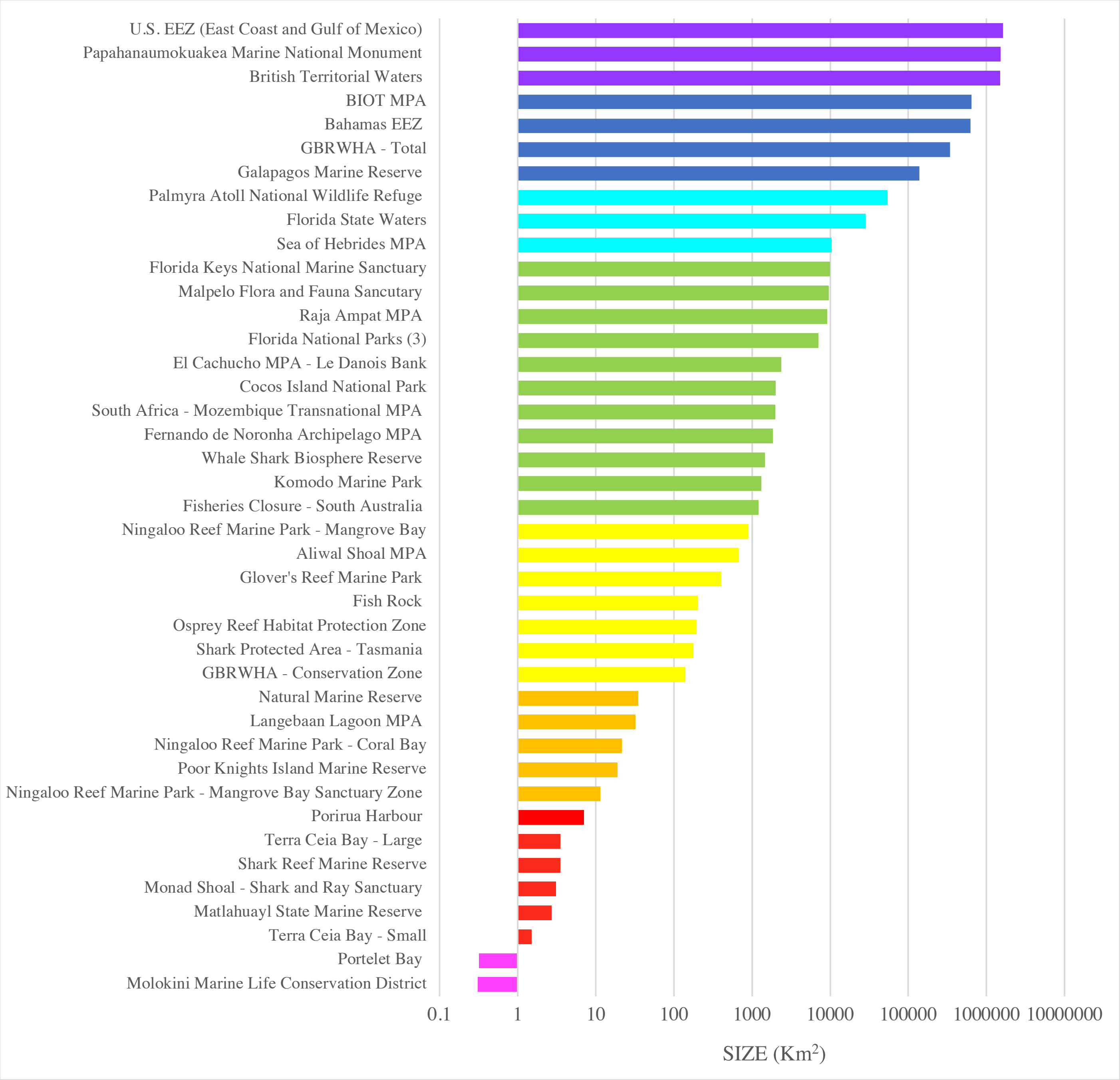

Figure 10. Size of the protected areas monitored in the papers reviewed in this study. Florida National Parks include the areas of Biscayne National Park, Everglades National Park and Dry Tortugas National Park. The Great Barrier Reef Marine Park (GBRMP) is represented twice, once as its total area and again to show a specific conservation zone that was monitored. Ponta do Ouro Partial Marine Reserve (PPMR) and iSimangaliso Wetland Park (IWP) together make up a transnational MPA between South Africa and Mozambique. Colours represent size category: pink = XX-small, red = X-small, orange = small, yellow = medium, green = large, light blue = X-Large, dark blue = XX-Large, purple = mega.

The IUCN World Database on Protected Areas (marine) is a dataset containing information about 7,361 MPAs (this includes all areas with a marine component; Figure 10). X-Small MPAs accounted for the greatest number, making up 24% by number, and only 0.03% by area, of the worlds designated MPAs (n=1779). Conversely, only six Mega MPAs exist worldwide and represent the smallest proportion, making up less than 1% by number, but accounting for 32% of total protected area.

4.7 Area Designation

The restrictions imposed on activities permitted within an MPA varied among sites with many authorizing combinations of activities frequently within different zoning types within the MPA (n=18). Eight MPAs had species specific restrictions, where harvesting and targeted fishing were prohibited. Multiple-use zones exist within 16 of the MPAs monitored although portions of all of these MPAs were subjected to additional area designations (i.e., no-take or restricted fishing). Fishing restrictions were also in 16 studies. Fishing restrictions ranged widely among the MPAs reviewed. Protected areas with a no-take zone occurred at sites where 15 of the reviewed studies were conducted. Strict no-take MPAs were present at sites monitored in 11 studies. A no-take designation was thus the most commonly stated characteristic of the studies considered. There was only one monitored MPA that included a No-go area and restricted all human activity within a part of its area.

4.8 Limitations and Outcomes

All but six studies were able of offer estimates of protected area effectiveness based on their monitoring strategies. Of these 39 studies, 56% (n=22) suggested that the MPA was unsuitable or offered little protection to the elasmobranch species monitored. In total this represented 60% (n=25) of MPAs reported in this review, however in some cases an MPA was reported as both effective and not effective in separate studies. Of the remaining studies that said the MPA offered significant or sufficient protection to encourage conservation and benefit the overall elasmobranch species' population (n=17), nine involved caveats. These caveats meant that while the MPA offered a species protection, it may only (or better) serve a certain subset of the population (i.e., juvenile or females).

5. Discussion

As the amount of managed or protected ocean area grows in response to governments' and society's determination to conserve troubled species and habitats, we collectively bear an increasing responsibility to ensure that these areas are effective and achieve their objectives. The creation of shark and ray directed sanctuaries is surging. This review provides many examples of how telemetric monitoring of elasmobranchs has contributed to MPA evaluations.

Results from this review revealed that telemetry has been used as a tool for tracking elasmobranch movements in order to monitor 42 different protected areas. Acoustic and satellite telemetry technology were used to monitor elasmobranchs within MPAs and precise methods (i.e., acoustic receiver arrays and satellite tag types) were tailored to best monitor each MPA and the targeted elasmobranch species. In general, these methods allowed the researchers to draw conclusions about the effectiveness of each protected area based on outputs like distribution patterns, abundance and site fidelity from telemetric data collection, in relation to the MPA's boundaries and regulations. Unexpected findings from my review included the common use of receiver hotspots to estimate elasmobranch protected area use and the diversity of species studied drawn from a variety of behavioural categories. Further, the use of telemetry data to study mortality rather than movement patterns alone was an anomaly among the reviewed studies and was reported a single time. The monitoring studies reviewed in this paper show that telemetry can help inform an MPA's contributions or limitations for different elasmobranch species, populations, life history stages, and individuals.

The earliest paper found that met the criteria for inclusion in this study was published in 2005, suggesting that the application of telemetry to monitor elasmobranchs in MPAs is relatively new. It's perhaps no surprise that the reviewed literature had an increasing trend in published studies from 2005 to the present. Reasons for zero published studies in 2007 and 2018 remains unclear. Electronic tags for fish tracking have been used since the 1950s, yet only more recently has tagging become readily and affordably accessible and been adapted for shark research (Cooke et al., 2013). Technological advancements such as a reduction in tag size, have meant researchers could begin tagging and tracking smaller species with a wider range of life history stages. Telemetry studies have also benefitted from increased acoustic receiver detection ranges, less invasive tag attachment methods, longer battery life in tags, reduced biofouling on external tags, and more accurate location estimates from satellites. These innovations' arrival coincided with an increasing need to evaluate conservation regimes and improve our knowledge of at-risk ecosystems and data deficient species.

Given that telemetry was primarily designed to better understand animal movements, nearly all the studies reviewed used this technology for that purpose, with one exception. Knip et al. (2012a), used existing data from an acoustic telemetry study (Knip et al., 2012b) to estimate levels of mortality in two coastal shark species within the GBRMP. This analysis offered insights into the possible protection afforded to these species by the MPA by measuring fishing mortality, natural mortality and total mortality. In undertaking this approach Knip et al. (2012a) extended the utility and use of passive acoustic telemetry data for MPA monitoring and evaluation. They estimated the number of individuals surviving (individuals continuously or recurrently detected within the study site), the number of natural mortalities (individuals whose movements ceased or changed drastically within the study site), and the number of removals from the population (individuals from which signals were lost within the study site, such as removal by fishers, or individuals taken by fishers outside the study site) throughout the study duration.

Acoustic telemetry is also useful for evaluating post-release mortality of fish from catch-and release sport fishing, or animals that are released as by-catch. Short-term acoustic telemetry has been used to asses such mortality in the past (often with active tracking), however, there are few examples of any kind assessing post-release survivorship over the long-term (Campana et al., 2009). Other electronic tag systems have been used to assess post-release mortality in sharks, including archival loggers like PSATs (Campana et al., 2009; Hutchinson et al., 2015; Hammerschlag et al., 2011), but were not applied in the reviewed studies.

Elasmobranch monitoring in MPAs has been concentrated in temperate and tropical regions, with no examples found in polar regions. Elasmobranch are species-poor in the Arctic and until very recently there were very few Arctic marine protected areas. Add to this the difficulty of accessing Arctic sites, and the expense of purchasing and shipping the equipment needed to work within extreme cold climates and it is understandably unsurprising to find so little done with Arctic sharks, skates and rays. By contrast, regions like the Indian and Pacific Oceans, which include several locations monitored in the studies reviewed (i.e., Great Barrier Reef Marine Park, Hawaii, Ningaloo), have more interesting and accessible habitats for conservation (e.g., shallow reefs and mangrove areas). Coral reef ecosystems are among the most biologically diverse anywhere on earth (Moberg & Folke, 1999). Capable of supporting bountiful marine life, they are often heavily exploited and overfished (Mora et al., 2006). For this reason, reefs are frequently the subjects of MPA protection.

In general, MPAs are thought to work better in habitats like reefs or seamounts that are home to highly aggregated, localized, or static species (or age groups) compared to other habitats that are used by highly mobile, migratory species (i.e., open ocean; Fulton et al., 2015). These characteristics explain why most of the species monitored in the reviewed studies were reef-dependent, had limited home ranges and were non-migratory (i.e., several species of reef sharks). MPAs work best for elasmobranch species or life stages that have these characteristics. For example, four studies monitored shark movements within the GBRMP around Cleveland Bay, Queensland, and investigated a total of six species; Black tip reef shark, Grey reef sharks, Silvertip shark, Bull shark, Pigeye shark, and Spottail shark (Table 1). These studies applied passive acoustic monitoring with acoustically tagged animals, and concluded that the GBRMP provided some protection to five of the species, more specifically for youngerls, females, and non-migratory species (the exception was the bull shark which proved to be migratory), but did not offer complete risk reduction from anthropogenic mortality (Chin et al., 2016; Espinoza et al., 2015a; Knip et al., 2012a; Knip et al., 2012b).

In places where more than one investigation took place in the same location, researchers often employed similar techniques and used some, if not all, of the existing acoustic telemetry infrastructure present throughout the area. Monitoring of the Ningaloo Marine Park in Western Australia followed 9 species (Broad cowtail ray, Common shovel nose ray, Porcupine ray, Reticulate or Honeycomb ray, Nervous shark, Blacktip reef sharks, Grey Reef shark, Whitetip reef shark, and Sicklefin lemon shark) in four studies sharing common acoustic receiver networks (Cerutti-Pereyra et al., 2014; Escalle et al., 2015; Speed et al., 2012; Speed et al., 2016). The ability to access shared infrastructure contributed to the concentrations of elasmobranch telemetry studies in regions like the Indo-Pacific.

Shallow reefs and coastlines can be prime places to put acoustic receivers, assuming there is minimal disturbance in these areas, (i.e., limited fishing activity) since they can be accessed easily to deploy, maintain, and offload data. This is also likely why nearly all MPA monitoring in reef habitats employed acoustic telemetry. Further, all studies in this review that monitored deep-water species also utilized acoustic telemetry, however, these studies took place in coastal areas such as estuaries and bays (Barnett et al., 2011; da Silva et al., 2013; Francis, 2013). Some deep-water species, like the common smooth-hound, are known to use coastal areas like estuaries as nurseries during juvenile life stages and move into deeper water with increasing age and body size (Francis, 2011). Similarly, gigantic/planktonic species like Reef mantas, that can have both high residency to relatively small areas for some periods of the year followed by larger pelagic movements, can benefit from protected areas around reef structures that serve as foraging and cleaning areas (Carlisle et al., 2019). MPAs in these areas may transiently benefit a wider range of migratory elasmobranch species such as tiger and scalloped hammerhead sharks, in addition to those that are reef-associated (Ketchum et al., 2014; Meyer et al., 2010).

Understanding habitat connectivity is important to evaluate the potential role of MPA networks (not within scope of this study, and currently this is relatively understudied). Telemetry will likely play a role in larger system monitoring and evaluation in the future. Hearn et al., (2010) placed eight receivers within the Eastern Tropical Pacific Seascape (inclusive of the GMR, Cocos Island National Park, and Malpelo Flora and Fauna Sanctuary; together making up an area over 2 million square kilometers), a known hotspot for pelagic species like scalloped hammerheads. Although these receivers did not cover the entire protected area, Hearn et al. (2010) could decipher fine-scale habitat partitioning within this area using a combination of acoustic telemetry strategies including passive and active tracking (supplemented by visual diver surveys). They concluded that within this larger ocean hotspot, smaller more discrete areas are preferred by scalloped hammerheads. They based this on disproportionate number of detections of particular individuals by certain receivers. Several other studies in this review also found that within MPAs individuals spent more time at specific locations and receiver sites (Bessudo et al., 2011). This kind of analysis can be useful for larger MPAs (size class large or greater) or when resources are limited. Likewise, understanding site preference within MPAs has important implications for definition of management zones.

Nursery areas have been widely recognized as vital habitats for sharks and rays for decades (Heupel et al., 2007). A better understanding of these areas and their contributions to conservation will improve overall management efforts. Investigating species' space-use patterns based on their sex and age has enabled the identification of nurseries, mating areas, and pupping grounds. Chin et al. (2016) used passive acoustic telemetry to determine patterns in residency of blacktip reef sharks in Cleveland Bay, taking sexual segregation into account. They found that females were long-term residents, remaining within the protected area for longer periods of time than males. Similarly, neonates and young-of-the year (YOY) animals were more resident than juveniles. This suggests that this coastal area, while not adhering to the classical definition of a nursery (see Heupel et al., 2007), supports resident reproductive females and appears to be an important area for blacktip reef shark mating and population survival. Conclusions from telemetry studies like this can contribute to the devising of specific protection for essential life history stages, and should be a focus of MPA monitoring.

In some cases, the location of an MPA was included within a larger area of monitored ocean space. For example, Graham et al., (2016) studied the movements of migratory shark species throughout a subset of Florida's protected marine space (several National Marine Parks and Wildlife Sanctuaries) while also tracking Great hammerhead, Tiger shark, and Bull shark movements throughout Florida's inshore state waters into federal waters off Florida in the United States' EEZ. They found that all the sharks remained within the EEZ but used the parks to a lesser extent, showcasing the limits of single protected areas and emphasizing that for many species larger management areas need to be considered for effective conservation and to meet recovery targets.

The ability to use telemetry to monitor changes in vertical migration is equally as important as monitoring horizontal movements to ensure that protected areas include (if necessary) the depths utilized by elasmobranchs. Brunnschweiler et al., (2010), used PSAT tags to determine diel patterns of Bull sharks in two different protected areas (Bahamas and Fiji) and the results led them to conclude that there was no particular biological significance to their vertical movements. Daley et al., (2015), implemented passive acoustic telemetry to monitor the diel patterns of a deep-water species, the Southern dogfish, within a fisheries closure area. A curtain array was deployed along the continental slope (see Daley et al., 2015 for configuration) at depths ranging from 225 – 600m deep. They concluded that dogfish vertical movements were explained by foraging for micronekton, in relation to ambient light levels and lunar phases. These insights allowed Daley et al, (2015) to determine that this closure incorporated an area large enough, and with sufficient depth range, to provide adequate protection to southern dogfish. These examples show that multiple telemetric methodologies may be needed to provide comprehensive information about an MPAs' vertical and horizontal protection.

In some instances, the reviewed studies monitored more than one species simultaneously. Similarly, three studies investigated a range of elasmobranch and teleost fish (Carlisle et al., 2019; Filous et al., 2017; Morel et al., 2013). Carlisle et al., (2019), used a mix of acoustic and satellite telemetry to monitor seven pelagic fishes including: Blue Marlin (*Makaira nigricans*), Sailfish (*Istiophorus platypterus*), and Yellowfin Tuna (*Thunnus albacares*). The purpose was to understand how an XXL MPA (BIOT) could protect large pelagics. Additionally, Morel et al., (2013) also used acoustic telemetry to passively monitor Ballan wrasse (*Labrus bergylta*) and several ray species, within a small, potential MPA location. Studies of multiple species can help researchers understand a broader ecological association among species and enable them to draw conclusions about species interactions. By the same token, these studies offer efficiencies by performing similar methods on many species in the same study.

Species monitored within MPAs may be chosen for several possible reasons, all of which are equally valid. First, species may be chosen based on the conservation objectives of the specific MPA. For example, Doherty et al., (2017) monitored Basking sharks within the Sea of the Hebrides, a Nature Conservation Marine Protected Area in Scotland. These sharks were a species of primary consideration for the area's designation. Secondly, species may be chosen to fill knowledge gaps about their current population status and ecological characteristics. In these cases, telemetric monitoring may provide baseline information about these species' movements in a certain location (see Le Port et al., 2008). The third reason that a species may be chosen for monitoring is based on opportunity. This occurs when monitoring is applied to individuals that are opportunistically or anecdotally caught when on tagging expeditions. This was how Carlisle et al., (2019) obtained large pelagic species to monitor within the British Indian Ocean Territory MPA (BIOT MPA). Opportunistic tagging can save resources in terms of time spent fishing (hours to weeks) and expenses, especially within very large MPAs. Finally, species may have also been chosen to help investigate the possible benefits for elasmobranchs when designating proposed areas for protection. Several of the reviewed studies a priori monitored elasmobranchs to inform the process of MPA designation. More typically, such monitoring is undertaken after the creation of a protected area and its management plan. For example, Heupel and Simpfendorfer, (2005) investigated the utility of long-term acoustic monitoring data for the evaluation of MPA design for a shark nursery area. The study aim was to determine the amount of protection offered within two hypothetical MPAs of different sizes. The authors concluded that both the smaller (1.5 km^2) and larger (3.5 km^2) size reserve would provide at least some protection for young sharks, however, the larger size would maximize conservation benefits.

Acoustic tags are the most commonly used telemetry technology to monitor elasmobranchs in MPAs. Their predominance may be related to several practical and/or logistical reasons. Acoustic telemetry offers several benefits over satellite telemetry including its lower tag cost, tag longevity, availability of tags in different sizes many of them small, data robustness and reliability. A single satellite tag can cost upwards of $3,000, making the cost per tags more than 10 times that of acoustic tags (Reine, 2005). However, depending on the application of these tags, the cost and benefit of using a given technology over another can vary. Unlike satellite tags, acoustic tags can be implanted into an animals' body cavity and thereby decreasing the risk of tag shedding, a common operational risk of externally attached tags. The flexibility of acoustic tag application (i.e., internal or external tag attachment) may increase their research utility. Relatively small animals are amenable to anesthesia and surgical implantation of tags. By contrast, external tagging may be safer and more practical for very large and aggressive sharks.

Acoustic tags (dependent on battery life, addressed in the following section) can last for up to 10 years and as long as receiver arrays are maintained, continue to transmit and collect data over this period. In the reviewed studies, the average MPA monitoring duration using acoustics was two years, whereas satellite telemetry averaged less than one year over all studies. Thus, the use of acoustic tags can increase the total amount of data and consistency for long-term monitoring. Short term studies, often less than a year, would not provide adequate data to fully document animal responses to seasonal variability (Oliver et al., 2019).

Acoustic tags, however, have limitations. "There is a general relationship between transmitter weight (grams), operational life of the tag (days or months), and minimum acceptable fish size (kilograms), and acoustic signals can be degraded by a number of factors including: thermoclines, vegetation, engine noise produced by passing boats, and high levels of suspended sediment" (Reine, 2005). Thus, the habitat in question must be thoroughly considered before acoustic receiver deployment. This might mean that certain MPAs are unsuitable for acoustic monitoring, including those with large bathymetric contours or a rugose substrate, in the deep-sea, in areas of high vessel traffic with noise that interferes with detections, or in cases of extreme sedimentation that can greatly reduce receiver detection range. Passive acoustic telemetry is limited in its ability to track species outside of a receiver array, unless the tag is compatible with other receiver networks located outside of the MPA. Active acoustic telemetry is also limited by its requirements of continual use of human resources. These constraints include the available personnel, crew limitations (i.e., food, sleep, pay), vessel requirements (i.e., fuel), physical barriers (i.e., too shallow, tides), and weather.

When the purpose of animal tracking is to monitor an MPA, acoustic arrays can provide continuous monitoring over large spatial areas. Both the areas where the animals are detected, and those that they avoid, provide useful information about habitat use and animal ecology. Yet, fully automated acoustic receiving arrays can still cost tens of thousands of dollars. These arrays, however, can be used for multiple purposes and over longer periods than satellite tags.

An acoustic receiver array must be designed in a way that will best inform the study objectives. For example, the gate arrangement described from some of the studies reviewed here were constructed to document the movement of elasmobranchs into and out of the target study area. Natural geography can aid in array configuration. Gates are often used in semi-enclosed bays or along river systems whereas linear arrays like those used by Daley et al., (2015) can be useful for understanding species movement along a gradient of depths in an MPA such as for an MPA located along the upper continental shelf. Evenly distributed arrays like those used by Francis (2013) in Porirua Harbour, New Zealand, and Chin et al., (2016) in Cleveland Bay, Australia, allow coverage of nearly the entire study area and ensures that any tagged individual within the MPA are detected. Within each of these examples, it is up to the discretion of the researcher(s) to determine if an acoustic array will place receivers so that detection ranges overlap or not. The choice for either option may be limited by the availability of resources (i.e., number of receivers) or the total area of study (i.e., size of the MPA). Overlapping arrays decrease the likelihood of an individual going undetected within the area or passing through a gate without record. Non-overlapping arrays, however, may allow for a more general use of resources over a larger area and reduce redundancy of detections. Similarly, some studies used single or more widely separated receivers at representative locations (or "hotspots") to characterize space use. The number of receivers used for these arrangements is greatly reduced. Oliver et al., (2019) used just four receivers placed in pre-determined hotspot areas around the Monad Shoal (Shark and Ray Sanctuary; ~3km^2) to investigate pelagic thresher shark movements. Many studies that used these techniques chose receiver placements based on existing knowledge of shark and ray movements in the area (Dewar et al., 2008; Setyawan et al., 2018; Hearn et al., 2010).

While acoustic telemetry has most often been employed with bottom dwelling, deep-water, and non-migratory species, satellite tags are used more often to study gigantic/planktonic, oceanic, and migratory species. By analyzing animal movements using PSAT data, Howey-Jordan et al., (2013) could estimate the percentage of time Oceanic Whitetip sharks spent within the Bahamas EEZ, an area where longlining is outlawed. In this very successful study, all the tags remained attached to the animal until their pre-programmed release date. This study was also able to track sharks' movements into other national jurisdictions, broadening the scope of the monitoring area. Using SPOT tags, Daly et al., (2018) determined the core habitats used by Tiger sharks and their incorporation of areas located within protected areas in South Africa and Mozambique. SPOT tags were also used by Graham et al., (2016) to study migratory species' space use overlap with MPAs throughout Florida and the Bahamas. These kinds of analyses are directly informative for MPA evaluations; however, not all species can tolerate SPOT tags. Because SPOT tags also require the device to break the water's surface to transmit data to Argos satellites, the species that can be monitored with SPOT tags must have frequent contact with the surface to generate good data quality (Hammerschlag et al., 2011). This is evident from the published studies available using SPOT tag. They are employed on planktonic species like the Giant Manta or Basking shark (Graham et al., 2012; Doherty et al., 2017) that spend time feeding at the surface. Deep-water or bottom dwelling species would not be effectively monitored using SPOT satellite technology.

Due to the diversity of information recorded by satellite tags, several of the studies reviewed were able to employ satellite tags to overcome typical species limitations and extend a study's spatial boundaries beyond those typically capable of being covered by acoustic tags. Satellite telemetry continues to provide estimates on space use even when an individual is outside of the MPA thereby providing useful data on other habitat use areas, reference sites and potentially mortality estimates. Satellite tags can provide months' worth of high-precision data on a single individual, making them a more efficient strategy for monitoring remote or highly migratory species (Reine, 2005). For example, Le Port et al, (2008), published the first PSAT data for a stingray species by tagging two Short-tailed stingrays and monitoring their movements within the Poor Knights Island Marine Reserve, New Zealand. The small sample size of this study limited the overall conclusions, but depth profiles from the PSAT tags revealed that these stingrays utilized water deeper than that found within the MPA. Rodriquez-Cabello et al, (2014) used PSAT tags to study leafscale gulper sharks, a deep-water species, and revealed their highly mobile lifestyle. However, because these sharks spent time at depths below 500m where light is scarce or absent, ambient light levels could not be used to estimate geo-locations. This is a common limitation of PSAT tags for monitoring deep-sea species. Instead, Rodriquez-Cabello et al., (2014) used tag temperature and depth data, plus the tag's pop-up and release points to estimate the animal's movement track. Rodriquez-Cabello et al. (2016) also noted that deep-water PSAT track reconstructions were greatly aided by Argo float temperature profile data from the regions where the animals were tracked.

Four studies used a combination of acoustic and satellite technology. In one study (Meyer et al., 2010), both acoustic and satellite tags were used to monitor the same individuals (deemed 'multi-tagging' by the authors) and the authors concluded that this allowed for a more comprehensive analysis of the animals' movements than using one method on its own. For example, the authors noted that tag detections at receivers could provide calibration points for estimated positions from satellite tracking data, improving track accuracy. Satellite tags in turn provided information on positions of the animals when they were outside of the range of acoustic receivers. An important application of multi-tagging was the increased duration of the study. After satellite tag transmission stopped, acoustic telemetry enabled continued tracking due to the longer battery life of the acoustic tags. Moreover, the application of multi-tagging may be particularly useful for remote MPAs (such as the PMNM described earlier, but also including other MPAs in the Large and greater sized MPA categories). Multi-tagging is also particularly useful for infrequently encountered species in order to maximize the data collected from rare capture and tagging events (Meyer et al., 2010).

The average size of studies monitored by satellite telemetry technology is hundreds of thousands of square kilometers larger than studies monitored with acoustic telemetry. One study was not included in protected area size analysis because it was not provided in the original paper, nor could size be estimated or found elsewhere. Satellite studies averaged less than one year in duration. This average might even be an overestimate due to staggered satellite tag deployments and the combined methods with acoustic data collection time in some studies, as single satellite tags typically last only a few months.

According to the IUCN World Database on Protected Areas (2019), the largest MPA in the world is the Ross Sea Region MPA, covering 2.060 million km^2, 1.555 million km^2 of which is no-take. The second largest MPA is the Cook Island Marine Park (Marae Moana), covering 1.976 million km^2. The Papahānaumokuākea Marine National Monument currently holds the place as the third largest MPA by marine space, designating approximately 1.508 million km^2 as no-take. Mega MPAs worldwide cover a total of 8,841,413 km^2 accounting for roughly 32% of the global MPA coverage. There were several monitored areas or actions within the Mega MPA size range that provided protection to migratory animals but are not included in this review because the areas did not meet my definition of a protected area (ie., fishing restrictions within the US EEZ and protection of Basking sharks in the British Territorial Waters are not listed as MPAs by the IUCN).

Despite the size of the Mega MPAs monitored, the telemetry studies reviewed all concluded that even these very large MPAs have a limited role in protecting elasmobranchs. Southall et al. (2006) found that Basking sharks spent only 22% of their time within British Territorial waters where their harvest is prohibited. In contrast, Doherty et al., (2017) found that Basking sharks were provided nearly full protection in Scottish Waters. This suggests that MPA effectiveness is related less to size than to placement. However, size can still have an influence on afforded protection as Graham et al (2016) found that MPAs off the coast of Florida, USA where sharks are protected, represented only a small proportion of their core habitat use and that expanding these areas to include the entire US EEZ in the Atlantic and Gulf of Mexico would provide nearly full protection to the species tracked.

The variety of conservation strategies used to protect shark and ray species globally is highlighted by the range of protected areas restrictions reported in the reviewed literature. Fishing restrictions on certain species (often those facing the greatest extinction risk), or sharks and rays more broadly, are often imposed in larger ocean spaces to reduce or hopefully eliminate fishing mortality. The Bahamas EEZ (see Graham et al., 2016; Howey-Jordan et al., 2013; Brunnschweiler et al., 2010) is a designated shark sanctuary where longlining and commercial catch and trade of sharks is prohibited. Several other ‘shark sanctuaries’ have been created globally (notably Palau and the Cook Islands), and given their specific objectives to protect shark species, monitoring populations within these protected areas to assess MPA performance should be a priority. Measuring residence times, mortality rates, seasonality and movement patterns within these areas are key to understanding elasmobranch interactions with high risk activities (i.e., fishing). Thus, telemetry can provide a useful and adaptable tool to monitor and assess shark sanctuary effectiveness.

In many of the studies reviewed, telemetry was used to monitor MPAs with numerous zoning configurations, however, conclusions regarding the effectiveness of no-take and multi-use areas for conservation within a single MPA were not discussed. These studies generally cited the expanse of home ranges for the monitored individuals relative to the size of the associated MPA as the reason for ineffectiveness. The telemetry techniques discussed cannot directly evaluate potential anthropogenic stressors such as tourist interactions with sharks and rays. Combining telemetry with additional methods such as analysis of fishing patterns and effort, visual identification of species or individuals (see Dewar et al., 2008), BRUV technology (see Bond et al., 2012), or local or indigenous knowledge, can improve our understanding of MPA dynamics its influence on shark and ray populations.

Telemetry allowed most studies to estimate MPA effectiveness at providing protection for elasmobranch species. Effectiveness was often determined by the amount that a species' distribution overlapped with the geographic area of the MPA. Measures of site fidelity and CHUAs were common among studies and provided direct estimates of the time individuals spent within the MPA, or the percentage of the space they used within the MPA. The seven studies that made no claim to evaluating the effectiveness of the MPAs in which the work occurred still conducted telemetry investigations of elasmobranchs within their respective MPAs. In these cases, the prime driver for the telemetry studies may have been expanding on previous research rather than looking at MPA function (Rodríguez-Cabello et al., 2016). Some studies had small sample sizes, as was the case reported by Le Port et al. (2008) where only two rays were tagged. In this circumstance a credible evaluation of MPA effectiveness is not possible. No study reported that inability to evaluate effectiveness was related to the telemetry type.

5.1 Conclusions

Future elasmobranch monitoring within MPAs will be critical to ensure continuing conservation efforts are producing positive results. Telemetry can provide precise spatial and temporal data on animal distributions and given the wide variety of technologies available for tracking elasmobranchs, can be used in many ways and nearly all environments. Based on the findings of this review, telemetry is a useful and likely underutilized resource for achieving monitoring and evaluation goals. Limitations of this review include a relatively small sample size of studies, and the absence of studies that may have performed applicable research but were not caught in the database search net. Further, conclusions based on this review may be too general to apply to all elasmobranch monitoring in MPAs and should be considered carefully on a case by case basis.

6. The Laurentian Channel Marine Protected Area (LCMPA)

6.1 Laurentian Channel Overview

As a signatory of the CBD and Aichi Target 11, Canada has protected approximately 793,906 km^2 (13.81%) of its ocean territory as of August 1st, 2019 (Government of Canada, 2019). In April 2019, Canada designated the LCMPA, covering 11,580 km^2 (X-Large MPA), or 0.20% of its ocean area and creating the largest no-take fishing zone in the country's national waters (DFO, 2015; Figure 11). The primary objective of the LCMPA is "to conserve biodiversity through the protection of key species and their habitats, ecosystem structure and function, and through scientific research" (DFO, 2019). This area is characterized by a submarine canyon, where depths range from 100m to 500m and temperatures that stay within a relatively narrow range of roughly 3-5°C, making the area cooler than the surrounding continental slope (Kulka & Templeman, 2013). The LCMPA contains mud and clay substrate in deeper sections, while sand and gravel make up the shallower banks (DFO, 2011). The LCMPA sits within the 3Pn and 3Ps Northwest Atlantic Fisheries Organization (NAFO) divisions, with its western edge bordering on area 4Vn (Figure 12).

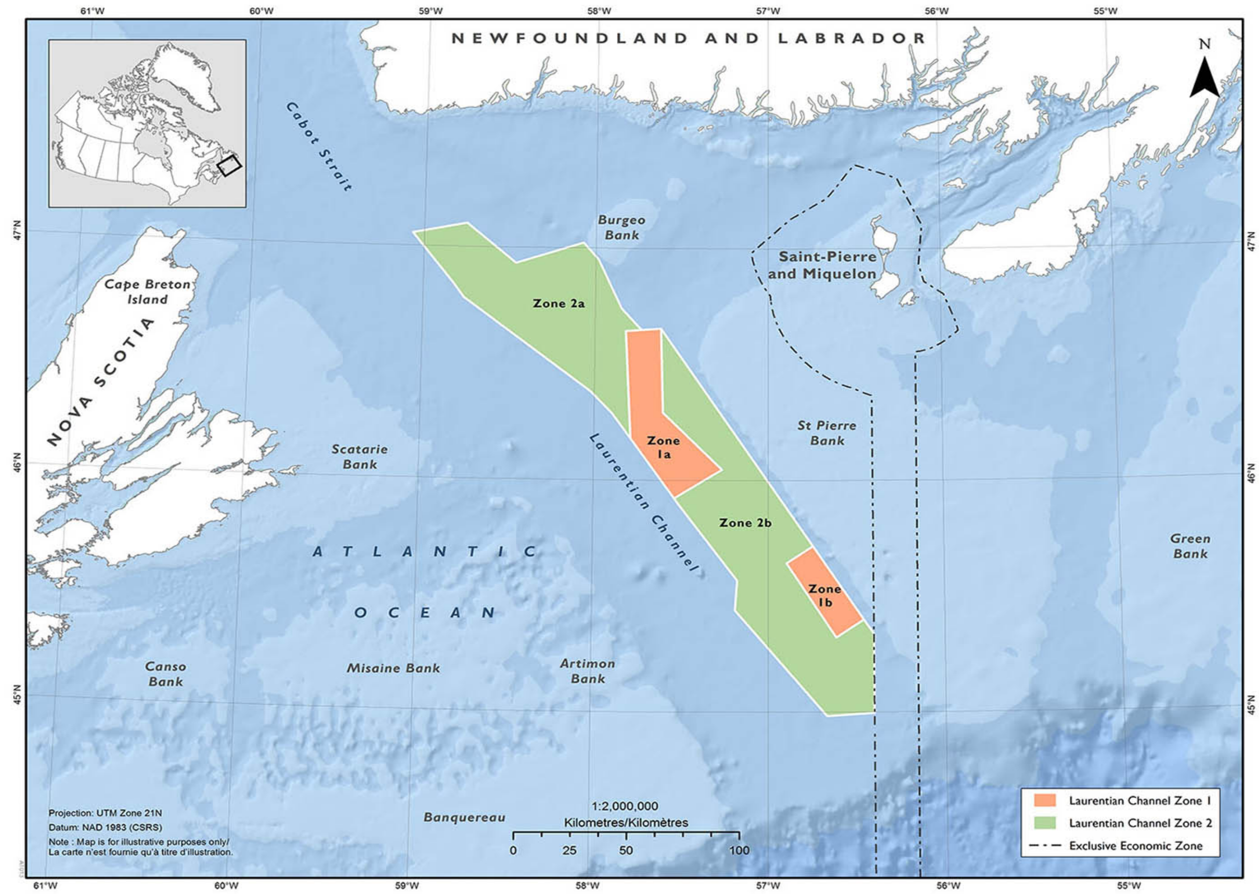

Figure. 11. Map showing the location and boundaries of the Laurentian Channel MPA (DFO, 2019).

Permitted activities within the LCMPA are limited to the following:

> " (a) navigation of vessels provided that there is no anchoring in Zone 1a or 1b; (b) fishing, other than commercial fishing, that is authorized under the Aboriginal Communal Fishing Licenses Regulations; (c) the laying, maintenance and repair of cables in Zones 2a and 2b, provided that it is not likely to destroy the habitat of any living marine organism in the Marine Protected Area; (d) any activity that is carried out for the purpose of public safety, national defense, national security, law enforcement or responding to an emergency; and (e) any activity that is part of an activity plan that has been approved by the Minister",

as per the Laurentian Channel Marine Protected Area Regulations (DFO, 2019).

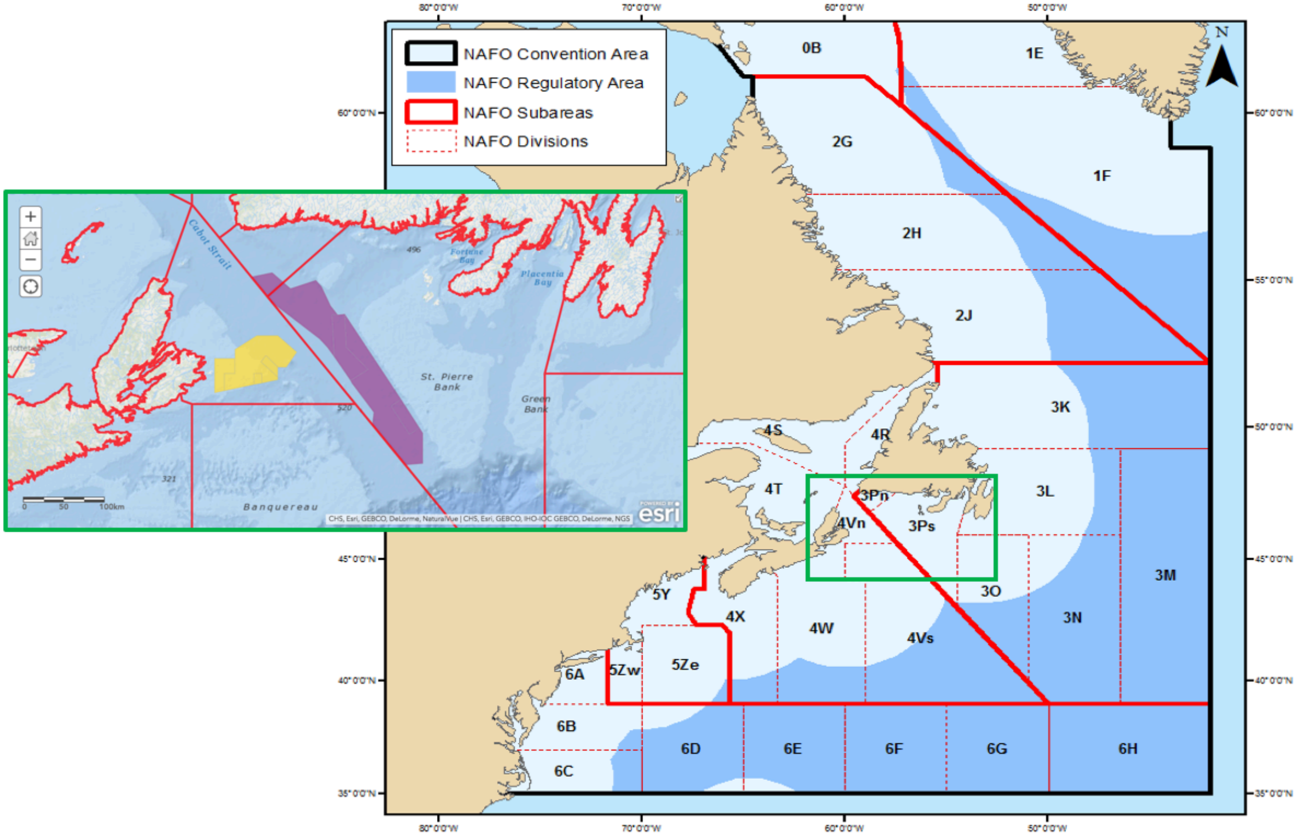

Figure 12. NAFO management area divisions and the location of the LCMPA (purple) and St. Anns Bank MPA (yellow) (DFO, 2019).

Conservation objectives (Table 2) for the LCMPA include protection for three species of elasmobranch, the Porbeagle shark, Black Dogfish, and Smooth Skate from commercial fisheries bycatch and seismic (oil exploration) activities (DFO, 2019). High year-round or seasonal concentrations of sea-pens and presence of at-risk species like Northern Wolfish (*Anarhichas denticulatus*) and Leatherback Sea Turtles (*Dermochelys coriacea*) also make this area important for conservation. Porbeagles are thought to reside in the LCMPA during summer months, and the boundaries encompass a mating ground for the species (Campana et al., 2002). Trawl surveys have shown that Black Dogfish and Smooth Skates occur in large numbers throughout the Laurentian Channel and the designated MPA area (Kulka, 2006; Simpson et al., 2012; Boag, 2014; DFO, 2019). All three species exhibit different life history strategies and occupy a range of ecological niches within the LCMPA, but the extent to which the LCMPA will conserve its target elasmobranch species is uncertain.

Table 2. Conservation and Research objectives for the LCMPA (DFO, 2015).

Conservation Objectives
1. Protect corals, particularly significant concentrations of sea pens, from harm due to human activities (e.g., fishing, oil and gas exploratory drilling, submarine cable installation and anchoring) in the Laurentian Channel.
2. Protect Black Dogfish from human induced mortality (e.g., bycatch in the commercial fishery) in the Laurentian Channel.
3. Protect Smooth Skate from human induced mortality (e.g., bycatch in the commercial fishery) in the Laurentian Channel.
4. Protect Porbeagle sharks from human induced mortality (e.g., bycatch in the commercial fishery, seismic activities) in the Laurentian Channel.
5. Promote the survival and recovery of Northern Wolffish by minimizing risk of harm from human activities (e.g., bycatch in the commercial fishery) in the Laurentian Channel.
6. Promote the survival and recovery of Leatherback Sea Turtles by minimizing risk of harm from human activities (e.g., entanglement in commercial fishing gear, seismic activities) in the Laurentian Channel.
Research Objectives
1. Advance the understanding of the distribution, biodiversity, health and integrity of cold water corals and sponges in the Laurentian Channel MPA.
2. Identify important as well as sensitive marine benthic areas and habitats in the Laurentian Channel MPA by supporting the conduct of scientific surveys, mapping and habitat association studies.
3. Advance the understanding of plankton variability in the area and locations of enhanced productivity supporting benthos, fish and cetaceans.
4. Advance the understanding of cetacean distribution, abundance and migration in the Laurentian Channel MPA.
5. Advance the understanding of the spatial and temporal distribution of sharks and shark bycatch, and quantify shark bycatch across all fisheries for species frequenting the Laurentian Channel MPA.
6. Advance scientific studies contributing to the identification and understanding of significant or critical habitat for SARA-listed species found in the Laurentian Channel MPA.

6.2 Methods

A literature review was conducted for the Laurentian Channel and the process of MPA designation. This included sources publicly available on the DFO website for the LCMPA and other sources identified from works cited as relevant to the three species of interest. Sources were chosen if their titles contained the names of at least one of the three species of interest

(Smooth skate, Black dogfish, Porbeagle), or one or a combination of the following words: sharks, skates, Laurentian Channel, monitoring, deep-sea, demersal, or pelagic. Two additional sources were included: "Placentia Bay-Grand Banks Large Ocean Management Area Conservation Objectives" and "A Critical Review of Monitoring Needs and Strategies for Marine Protected Areas and Areas of Interest in Newfoundland and Labrador". The principles enunciated in these documents were deemed highly relevant to this investigation. In total this literature search rendered 25 papers describing our current state of knowledge about the target species biology and revealing gaps in the current understanding of their distribution and utilization of the Laurentian Channel in general and more specifically the LCMPA.

6.3 History of LCMPA designation

There are several procedures that are followed in designating marine protected areas in Canada. For the LCMPA, the process began with the establishment of five Large Ocean Management Areas (LOMA) under the Oceans Action Plan I (OAP-1) within Canadian territorial waters. These included: the Pacific North Coast Integrated Management Area (PNCIMA), the Beaufort Sea, the Gulf of St. Lawrence Integrated Management Area (GOSLIM), the Eastern Scotian Shelf Integrated Management Area (ESSIM), and the Placentia Bay-Grand Banks (PBGB) which includes the Laurentian Channel area.

For each LOMA, science-based conservation objectives were developed in order to protect essential ecosystem components from damage (DFO, 2007). The conservation objectives established were meant to guide future integrated management measures within the LOMA (DFO, 2007). Conservation objectives were also based on previously identified Ecologically and Biologically Significant Areas (EBSAs), Ecologically and Biologically Significant Species and Community Properties (ESSCPs), Depleted and Rare Species, and Degraded Areas (DFO, 2007).

Conservation objectives were required to deal specifically with ecological outcomes and were intended to have measurable outputs that could be achieved within a specified timeline (DFO, 2013). Conservation objectives were also intended to have a set of indicators that could be tracked and evaluated over time. Monitoring of these indicators would be required to use least-invasive methods that did not harm the environment (DFO, 2013). Monitoring strategies were defined as "avenues employed to undertake the monitoring protocols" and included relevant equipment, techniques, quality control, timing, frequency and analysis of data. The monitoring could be carried out by DFO, government agencies, academia or others (DFO, 2013). Indicators needed to be replicable and when possible directly comparable with previous or ongoing research to allow for statistical testing (DFO, 2013). Reference sites inside and outside the MPA were also considered important to assess differences between protected and non-protected areas. MPAs would be considered successful when they meet their conservation objectives.

The Laurentian Channel area was first identified as an Area of Interest (AOI) in June 2010 under the Marine Protected Areas Initiative (Kulka & Templeton, 2013). Potential MPA sites are chosen based on criteria that require that they be sited within an existing LOMA and had previously considered as an EBSA (Kulka & Templeton, 2013). The Laurentian Channel sits at the western edge of the PBGB LOMA and was of interest due to significant features including: Black dogfish pupping and aggregation, Smooth skate (< 30cm) nursery, and multi-species migration through the area (fish, cetacean, pinniped) (DFO, 2007).

A biophysical overview of the Laurentian Channel AOI was conducted in 2011. This overview was a key component for the evaluation and implementation of the AOI, leading to its eventual MPA designation. Contributions to this assessment included the examination of species distribution and habitat use for 22 demersal fish that occurred within the LC AOI, by comparing their catch rate, depth and temperature inside and outside of the area being considered (Kulka & Templeton, 2013). Species selection was determined based on their abundance within the AOI and surrounding area which includes all the NAFO 3P divisions, the edge of 3O to the east and subdivision 4Vn to the west. Species selection also included 13 demersal fish (Kulka & Templeton, 2013). One of several research methods used to gain insight into species distribution and abundance within the Laurentian Channel was trawling surveys. Trawl surveys have helped to identify species within the Laurentian Channel, and habitat use within the protected area boundary for commercial and non-commercial species. Finfish species distributions throughout the Laurentian Channel have been determined using DFO fisheries-independent trawl surveys in NAFO division 3P each year in April-May since 1972, using a stratified random sampling design (DFO, 2015). Additionally, Campelen 1800 Shrimp trawl survey series have been ongoing annually between 1994 and 2009, and catch numbers and rates have been compared inside and outside the LCMPA boundary (e.g., within NAFO divisions 3P and 4V; DFO, 2011). Throughout these surveys, species abundance was reported as the percentage of the total catch over the entire study area, inclusive of all survey data. These surveys, however, did not take into consideration seasonality or annual differences in catch (DFO, 2011). While trawl surveys can be useful in determining species presence and abundance over time they do not capture larger pelagic species, including sharks like Porbeagles. Trawl surveys are less suited to document fine-grained patterns as they cover a large area of the seafloor, yet are useful for knowing if a species is present and for mapping long term distribution and abundance data (Baker et al., 2012b).

During the process used to assign conservation objectives for the PBGB LOMA, 11 EBSA areas were identified and subsequently scored into three tiers of priorities (high, moderate and low). The Laurentian Channel area was designated as a moderate conservation priority, given its ecological importance yet relatively little exploitation and historical disturbance (Stanley et al., 2015). Redfish (*Sebastes mantilla*), Porbeagle sharks and Harp seals *(Pagophilus groenlandicus*), were identified as priority species within the EBSA conservation priority matrix (DFO, 2007). National guidelines were issued for the preparation of Conservation Objectives for LOMAs. These guidelines were used to draft conservation objectives for the LCMPA, with the draft documents being reviewed at a Regional Workshop. Input from the workshop was used to revise and improve the draft.

Following the official designation of the LCMPA in April 2019, the Department of Fisheries and Oceans Science division is now required to provide advice on indicators and protocols for monitoring conservation objectives in support of the Health of the Oceans Initiative (DFO, 2015). Monitored indicators will contribute to the broader management plans for the site and serve to help evaluate the effectiveness of the LCMPA. Suggested indicators for monitoring include direct, indirect and anthropogenic pressure indicators (DFO, 2015). Direct indicators provide information on the status and trends of species covered by the conservation objectives. Indirect indicators include biotic and abiotic components that help inform causes of changes in conservation objectives. For the purpose of this document, only the indictors potentially relevant to elasmobranch species are considered (Table 3; see also DFO, 2015).

Table 3. Indicators proposed by DFO (2015) for the monitoring of the elasmobranch species outlined in conservation objectives. Direct indicators are highlighted in grey boxes, whereas white boxes contain indirect indicators.

Species	Indicators
Black Dogfish & Smooth Skate	Biomass, size distribution, frequency, occurrence
	Bycatch adjacent to the MPA
Porbeagle sharks	Frequency, occurrence
	Bycatch adjacent to the MPA

6.4 Monitoring tools and filling knowledge gaps for LCMPA priority elasmobranchs.

For pelagic species like Porbeagle sharks, experimental longline surveys have been conducted in order to investigate population status, abundance, and habitat use (DFO, 2015). However, there are currently no plans to repeat these surveys in the near future, but this should be considered for the monitoring of the LCMPA every 5 year as recommended by DFO (2015). DFO (2015) has also acknowledged the potential of acoustic telemetry to inform species movement in the LCMPA, where:

> "Acoustic telemetry tagging in conjunction with installation of acoustic receivers can be useful to inform MPA managers and scientists about migration patterns of individual Wolffish, Porbeagles and other sharks, and Leatherback Turtles in the LC MPA. Migration patterns and habitat use (e.g., Porbeagle mating grounds, Black Dogfish pupping grounds, Wolffish nursery areas) of tagged animals equipped with acoustic tags can be tracked with acoustic receivers installed on the seafloor to record signals as they swim near a receiver."

Lewis et al (2016) indicated that telemetry would be a valuable tool for the LCMPA. The application of telemetry and careful methodological selection can help to fill in several knowledge gaps (Table 4). In this review telemetry is considered primarily for the examination of movement and habitat usage of elasmobranchs, however other applications include assessing seismic survey impacts on these populations and species association through predation. Despite practical use for these purposes (see Wardle et al. 2001; and Berejikian et al. 2016) but review of this methodology was beyond the scope of this study.

Several acoustic telemetry studies in Atlantic Canada have collected data to monitor shark movements. Both acoustic and satellite tagging methods have been deployed for several species throughout the DFO Maritimes and Newfoundland Regions. PSAT tags were used to track Blue (*Prionace glauca*) (n=4) and Porbeagle sharks (n=1) (Kerstetter, et al., 2004; Pade et al., 2009; Campana et al., 2010). Information gathered from these tags such as depth, temperature and light intensity, were used to determine where and when these animals moved throughout the Laurentian Channel. From 2007-2009, fisheries independent surveys were conducted to monitor baseline populations of Porbeagles and tag individuals (Campana et al., 2015). This survey included the use of 50 fixed telemetric listening stations in the Georges Bank, southern Newfoundland Region. The spacing of these receivers was non-uniform and more heavily distributed throughout the Scotia Shelf. Given the scale of the LCMPA and the importance of the information that is being sought, a well-planned receiver coverage will be required.

Research objectives outlined by DFO (2015) in support of conservation objectives as discussed above for the LCMPA include increasing the understanding of shark distribution and incidences of bycatch in both time and space for species of conservation priority (Table 3; Lewis et al., 2016). While understanding distribution within and around the LCMPA is critical, rates of bycatch within the LCMPA should be zero given its no-take status. However, understanding the risk posed to species outside the LCMPA may still provide valuable information regarding the protected area's contributions to species recovery targets. Gathering baseline knowledge will help in the monitoring and evaluation process of the area over time, allowing researchers to identify trends and processes that contribute to the biodiversity and unique ecosystem within the Laurentian Channel. Monitoring objectives will involve selecting reference sites, setting long-term monitoring goals, and designing effective data management systems (DFO, 2015). Reference areas will be essential to determining effectiveness of the LCMPA and will include similar habitats for species of interest outside the MPA.

Table 4. List of elasmobranch species addressed by conservation objectives for the Laurentian Channel MPA, and their associated information gaps as identified by Lewis et al. (2016). Points in bold text can be addressed using telemetry. Points denoted with an asterisk (*) indicate information gaps that may be filled using telemetry studies but for which the methodologies were explicitly considered in this review.

Species	**Identified Information Gaps (Lewis et al., 2016).**
Black Dogfish	❖ Incidence of bycatch and discards in all fisheries in 3P ❖ Accurate estimates and timing of significant bycatch of Black Dogfish in all fisheries in NL waters which capture dogfish require reporting of catch and discards by species. ❖ **Timing of annual pupping through seasonal sampling of Black Dogfish populations.** ❖ **Information on specific habitat requirements for YOY, immature and mature Black Dogfish.** ❖ **Effects of seismic surveys on all life stages of Black Dogfish**.* ❖ **Information on Black Dogfish movements and migrations by age and maturity stage.** ❖ **Trophic role of Black Dogfish and their associations with other organisms ***
Smooth Skate	❖ Accurate estimates of significant bycatch of Smooth Skate in all fisheries. ❖ **Specific habitat requirements for YOY, immature and mature Smooth Skate.** ❖ Life history parameters and reproductive cycle (especially timing of skate egg extrusions by spawning females on nursery grounds) for this area of the species' range. Information regarding size at maturity and growth patterns is also required. ❖ **Effects of seismic surveys on all life stages of Smooth Skate*** ❖ **Distribution and abundance in Subdiv 3Ps and the LC MPA along with movements of smooth skate within the area**
Porbeagle Shark	❖ Accurate estimates of commercial longline and gillnet bycatch of Porbeagle (Simpson and Miri 2014). ❖ **Post-release mortality rates of Porbeagle bycatch from particular fishing gears (especially gillnets, longlines, and weirs).** ❖ **Effects of seismic surveys on all life stages of sharks.*** ❖ **Movements within the LCMPA (especially of pregnant females), and presence of YOY and immature Porbeagle.** ❖ **Seasonal estimates of Porbeagle abundance**

6.5 Species Profiles

6.5.1 Porbeagle Shark

Porbeagle sharks are a pelagic species and member of the Lamnidae (Mackerel sharks) (Campana et al., 2015). They can maintain core body temperatures approximately 7-10°C higher than ambient water due to the presence of a countercurrent heat exchange system that helps retain heat from metabolic processes (Joyce et al., 2002). They have a generation time of approximately 18 years, reaching maturity at 13 and 8 years, and 174 cm and 217 cm (fork length) for males and females respectively, and females produce roughly 4 pups per year with an estimated gestation time of 8 to 9 months (Simpson & Miri, 2013; Campana et al., 2002; Jensen et al., 2002; Natanson et al., 2002; Campana et al., 2015). Length data collected from Porbeagles showed a bimodal distribution, inclusive of both sexes, with two distinct groups ranging from 90-100 cm and 170-210 cm, generally distributed into juvenile and adult grouping (Simpson & Miri, 2013). Porbeagles are more frequently caught in deep basin areas or along the shelf edge (Campana et al., 2015). Their preferred temperature seems to be around 5-10°C but they have also been observed within the 8-13°C range (Campana et al., 2013). Stomach content analysis has shown that Porbeagle diet consists largely of teleost fish (up to 91% of their diet by weight) and is supplemented by cephalopods and pelagic fish in the spring, and groundfish in the fall (Joyce et al., 2002).

Porbeagles live throughout temperate waters with a North Atlantic population residing along the continental shelf of eastern Canada and North East United States (Campana et al., 2010). These sharks use the waters of Southern Newfoundland Region, including the LCMPA and Georges Banks throughout the summer and fall months to mate, yet their pupping grounds remain a mystery (Stanley et al., 2015; Campana et al., 2010). In comparison to areas surrounding the LCMPA, the species' presence reported from Fisheries Observer data inside the protected area is low (Stanley et al., 2015). Tracking studies with PSAT tags that record position, temperature and depth at one minute intervals have shown that all tagged mature female Porbeagles made 2000 km seasonal migrations to the Sargasso Sea in the late winter, seemingly to pup (Campana et al., 2010). These females moved south from eastern Canada at depths down to 1360 m, travelling in cooler waters below the Gulf Stream (Campana et al., 2010). In contrast, males and immature animals, females remained in cooler northern waters of the Atlantic Ocean. Porbeagles also have a Northeast Atlantic population, however, there is thought to be limited mixing between the two populations and they are thus distinct from one another (Campana et al., 2015).

Porbeagles sharks face several threats in the Northwest Atlantic with the primary threat being bycatch in longline and gillnet fisheries (Simpson & Miri, 2014; Lewis et al., 2016). Porbeagles are not often caught by trawl gear, having been caught in fisheries independent trawl surveys only eight times (Simpson & Miri, 2013). Current low numbers of porbeagle sharks have resulted from of the cumulative impact of fisheries bycatch from industries including swordfish and tuna longlining, groundfish longline and gillnetting, and otter trawling. The impact of other anthropogenic effects on this and other large pelagic species within the NW Atlantic are less understood. This includes the possible influence of noise disturbances, marine pollution, oil and chemical spills, pipelines and submarine cables may have on these populations. The majority of the porbeagle catch occurs in Newfoundland Region waters along the Grand Banks in NAFO Division 3LNO (Campana et al., 2015).

COSEWIC recommended the porbeagle shark for listing as Endangered in 2004, yet at present it remains unlisted under the Species At Risk Act (SARA) (Lewis et al., 2016). The recovery potential of the Northwest Atlantic Porbeagle population was reassessed in May 2014 (Campana et al., 2015). In response to decreasing Porbeagle numbers following a collapse in population in the 1990's, the targeted porbeagle fishery directed fishing industry was suspended in 2013. In 2009, it was estimated that the Northwest Atlantic Porbeagle population was at only 22-27% of its size in the 1960s (Campana et al., 2015). Of particular concern was the fact that the number of mature females in this population was reduced to just 16% of historical numbers (Campana et al., 2015). In Canadian waters, it is estimated that Porbeagle bycatch has been approximately 110 tons annually since 2010 (Campana et al., 2015). Recovery targets for Northwest Atlantic Porbeagles have been set at achieving 80% of female spawning stock numbers at the point of maximum sustainable yield, for a minimum of three generations. It will take roughly 54 years to reach this level given current population sizes and reproductive rates (Campana et al., 2015).

A key challenge for generating accurate population assessments for the North East Atlantic population of Porbeagle is the lack of reliable data on the fishing mortality of these sharks, particularly for bycaught fish taken outside of the Canadian EEZ. Formal statistical records are limited and therefore assessments of porbeagle catch and discards are not available.

Porbeagles are estimated to be the most common bycatch species in the NAFO Division 3Ps and the Grand Banks fisheries for Atlantic cod, Monkfish, Hake and skate (Simpson & Miri, 2013). Gillnet and longline fisheries such as those for cod, swordfish and tuna are the major source of porbeagle bycatch. These animals are required to be returned to the ocean but are frequently already dead when this occurs (Simpson and Miri, 2013; Campana et al., 2015). Very limited observations of hooking mortality rate for live-released bycaught Porbeagles suggest that the rates vary considerably depending on the target species of the fishery (Campana et al., 2015). The average mortality rate recorded by onboard observers was 44% but increased to 65% when the target species was blue fin tuna (*Thunnus thunnus*) and decreased to 30% when the target was swordfish (*Xiphias gladius*; Campana et al., 2015). However, the limited number of observations means that the post-release mortality of Porbeagles caught for research purposes, and as bycatch are uncertain. A research survey that used pelagic longlining to catch and tag 29 porbeagle sharks, observed that 6 individuals died soon after release (Campana et al., 2015). Low catchability in demersal survey trawls conducted in the NL Region makes estimating the species distribution an added challenge, and requires alternative methods. Estimates of Porbeagle bycatch are often incomplete as catch records may not include enough species-specific detail, be misreported or not include data from foreign vessel fleets. Formal statistical records are limited and therefore assessments of porbeagle catch and discards are not available. Bycatch within and around the LCMPA prior to its official designation has been nearly zero since the fisheries closure for porbeagles in 2000, therefore impacts of the protected area are likely to be positive, yet limited (Stanley et al., 2013).

6.5.2 Black Dogfish

The Black dogfish is a deep-water species distributed throughout the Atlantic from Greenland to South America on the west, and to Southwest Africa in the east. There is a high concentration of this shark in Canadian slope waters, including the Laurentian Channel (Kulka 2006) and the species abundance is lower in sponge fields compared to coral assemblages throughout the Grand Banks region (Baker et al., 2012a). The species' highest concentrations occur within the Laurentian Channel area and it is one of two species that appear to have their greatest abundances inside rather than outside the LCMPA (Kulka, 2006, DFO, 2011, Kulka & Templeton, 2013). This species' is generally thought to stay in close proximity to the substrate and its distribution is thought to be influenced by water temperature and depth. Black dogfish seem to avoid temperatures < 3.8°C and depths > about 350m respectively and are most densely distributed between 400 and 550m and at 4.6-6.5°C (Kulka & Templeton, 2013).

Black dogfish distribution also appears to be influenced by an individual's size and sex (DFO 2011). Black dogfish can reach a total length up to 107 cm, reaching maturity at around 55 and 65 cm for males and females respectively (Stanley et al., 2015). Late stage embryos can be up to 19cm (Stanley et al., 2015). Their highest concentrations occur within the LC area and it is one of two species that appear to have its greatest abundance inside rather than outside the LCMPA (Kulka, 2006, DFO, 2011, Kulka & Templeton, 2013). Most large catches of black dogfish (by volume) are within the Laurentian Channel.

Autumn surveys of the Newfoundland Region cover the 3Ps area, where the most concentrated black dogfish aggregations are thought to occur. Due to a lack of sampling at other times of the year, seasonality in the distribution of this species is still largely inferred. The presence of mature female and young-of-the-year Black dogfish in the shallow portion (<400m) of the Laurentian Channel indicates it likely serves as a pupping ground, however, the timing of these events is still unknown (Kulka, 2006; Boag, 2014). The Laurentian Channel is the only area in Canadian waters where Black dogfish pupping is known to occur (DFO, 2011 As the pups grow, they move into deeper areas until they begin to mature at which point they make their way into slope waters (Kulka, 2006; Kulka &Templeton, 2013). Juveniles constitute most of the Black dogfish catch within the LCMPA. The diet of Black dogfish is composed mostly of crustaceans, fish, cephalopods and jellyfish (DFO, 2011). This species, while not targeted, is often caught incidentally as bycatch. This catch is estimated at approximately 60 to 100 tonnes annually (DFO, 2011). Bycatch in Canadian waters averaged 68 tonnes annually between 1996 and 2005, virtually all of it from the Greenland halibut fishery prosecuted within the LC area (Kulka, 2006) Habitat destruction and seismic activities also threaten black dogfish populations throughout the Northwest Atlantic.

Black dogfish movements throughout the LCMPA are poorly understood. Limited evidence suggest that their populations may be declining as the species bycatch is composing a declining fraction of the total catch of authorized fisheries in2003-2009, compared to 1996-2002 (Kulka & Templeton, 2013). The LCMPA is thought to be able to provide significant protection for the Black dogfish (Kulka &Templeton, 2013).

6.5.3 Smooth Skate

The Smooth skate is one of four species in the *Malacoraja* genus. Smooth skate have been found from the southern portions of Georges Bank to the Hopedale Channel on the Labrador Shelf (Kulka et al., 2006a). These are known as "soft skates" due to their small size and generally small body spines (Kulka et al., 2006a). Total length is generally around 67 cm, with length at 50% maturity being 50 and 47 cm for males and females respectively (Stanley et al., 2015). Fully formed juveniles emerge from egg cases at around 7-10 cm total length (Stanley et al., 2015). Smaller skates occur inside the Laurentian Channel and larger fish reside on the adjacent banks (DFO, 2011). While the size distributions of skates within these different areas is unknown, based on maturity studies performed by Sulikowski et al., (2007) where mature females ranged from 50.8 to 63.0 cm in total length and mature males ranged from 55.0 to 66.0 cm total length TL, it will be assumed that these examples would constitute skates of the 'larger' category. This species is most commonly found in waters around banks at depths ranging from 70 and 480m (Kulka et al., 2006a).

Trawl surveys have revealed that Smooth skates are present throughout the LCMPA, however, unlike the Black dogfish, the majority (56%) of the known smooth skate distribution in Canadian waters lies primarily outside of the LCMPA (Lewis et al., 2016; DFO, 2011). The species is benthic and their distribution seems most influenced by temperature and depth, with this skate's greatest abundances found between 5-6°C and 400-500m (DFO, 2011). Their distribution is also likely dependent on the availability of their small crustacean prey (DFO, 2011). This species is most commonly found in waters around bank areas at depths ranging from 70 and 480m (Kulka et al., 2006a). The main threats to this species is bycatch from bottom trawling, habitat degradation from oil and gas exploration and other anthropogenic activities that disturb their benthic habitats. Post-discard mortality is estimated to exceed 40% based on comparisons with other skates (Stanley et al., 2015).

Consistent DFO trawl surveys have been performed within the Laurentian Channel region and have been considered adequate to describe Smooth skate distributions (Kulka et al., 2006a). Smooth skates are the twelfth most abundant species within the LC area based on averaged catches from trawl surveys between 1996 and 2009 (Kulka & Templeton, 2013). Many smooth skates caught within the Laurentian Channel are juveniles. Catchability of skates in research trawl gear is generally low and likely underestimates their presence (Kulka et al., 2006a). In the surveys, skate distributions were patchy, with five areas identified where smooth skates were more commonly encountered, separated by large expanses where there were none observed (Kulka et al., 2006a). It is unknown whether these ‘distinct areas’ consist of genetically distinct populations or whether presently not understood environmental or social factors cause aggregations (Kulka et al., 2006a). Historically, smooth skate abundance across the species distribution (as measured by catch per unit effort in the trawl surveys) decreased significantly from the 1980’s until the 1990’s (DFO, 2011). In the Laurentian Channel explicitly, Smooth skate catches decreased 73% from 1971 to 2005 (Kulka et al., 2006a). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) evaluated the extinction risk status of smooth skates in Canadian waters in 2012 and recommended designating the Laurentian-Scotian shelf population a unit of ‘Special Concern’ (COSEWIC 2012). Many gaps in the understanding of these deep-water species still exist (Table 4), including about their life history traits, reproductive cycle, and distribution and habitat use differences between adults and juveniles.

7. Potential uses of telemetry in the LCMPA

It is both beneficial and feasible for monitoring of the LCMPA to incorporate telemetry to study the three priority species of elasmobranchs identified in the conservation objectives for this area. The review of telemetric methods to monitor elasmobranch species within MPAs can directly inform LCMPA monitoring strategies by providing examples of studies tracking similar species within similar MPAs. As an X-Large MPA having great depth, the LCMPA would benefit from both satellite and acoustic telemetry monitoring. In addition to the elasmobranchs, an acoustic receiver array within the LCMPA may assist with tracking of additional valued species that utilize this area and could benefit from MPA protection. These can include Basking sharks, white sharks (*Carcharodon carcharias*), blue sharks, and swordfish. Due to no-take zonation, the LCMPA should provide a complete relief area from fishing interaction risks, however, monitoring the extent of protection provided by this area over several seasons and various life histories for the three priority elasmobranch species will be essential to evaluating its effectiveness.

The following sections will highlight the practical advantages of using telemetry to foster data collection on priority elasmobranchs and to measure the effectiveness of the LCMPA into the future. These recommendations can inform the management plan for the LCMPA. Capture methods were outside the scope of this review and therefore are not explicitly addressed in LCMPA telemetry recommendations. Instead, examples of studies performed on similar species are offered as possible methodological references.

7.1 Porbeagles

The purpose of the LCMPA for Porbeagle sharks is to provide a refuge for their population from human induced stressors (e.g., bycatch in the commercial fishery, seismic activities). The current knowledge gaps potentially hindering the evaluation of this objective have been outlined by Lewis et al., 2016 (Table 4). To date, telemetry has been instrumental in providing a coarse understanding of porbeagle shark movement in the Canadian North Atlantic.

Although the Laurentian Channel is thought to constitute a Porbeagle mating ground, the species distributions and vulnerabilities with respect to pregnant individuals, YOY, and juveniles both within the LCMPA and throughout the Laurentian Channel are still largely unknown. Tagging efforts should be maximized in early to mid-summer to assess the population throughout their time in Canadian water. Moreover, targeting both mature females and younger (i.e., YOY and juvenile) Porbeagles should be a primary focus of research efforts. The species vulnerability to capture on longlines and by rods means that capture of specimens for tagging would likely be successful. Acoustic tags can be applied both internally or externally. Surgical implantation may be advisable where logistics permit because it removes the drag of the external tag and the wound that remains open where the external tag is anchored to the animal's body. Acoustic systems also enable the tagging of younger/ smaller individuals for which the relatively large satellite tags are unsuitable.

The post-release mortality rates of Porbeagle bycaught in various fishing gears, particularly gillnets, longlines, and weirs, is currently not well understood. Because the LCMPA is a no-take reserve, this gap is not directly relevant to this site. However, understanding the risk posed to Porbeagles by fishing gears outside of the protected area may inform the overall value of the LCMPA. Further, understanding capture and handling stress and their impact on post-release survival is critical for performing safe and effective tagging procedures. Post-release mortality for Porbeagles from research long-line sets has been reported up to 27% from PSAT collected data (Campana et al., 2015; Campana et al., 2016). For releases from commercial fisheries, the mortality estimates are higher, ranging from 30 to 65% depending on gear and target catch (Campana et al., 2015). Post-release mortality can be estimated using acoustic telemetry using methods adapted from Knip et al. (2012a) or using PSAT tags.

Satellite tagging will be a critical asset for porbeagle monitoring due to the species' highly mobile and migratory behaviour. Larger individuals, and especially mature females, would be able to accommodate multiple tag types. For example, a large female could successfully carry both a dorsal mounted SPOT tag and a PSAT tags. The application of satellite tags on younger individuals will depend on the animal's size and body condition. Satellite tagged animals could also concurrently carry passive acoustic tags, and longer-term acoustic telemetry can help to collect information towards long-term goals established for recovery targets described by Campana et al., (2015).

The benefits of multi-tagging can provide additional confidence in data generated from both satellite and acoustic tagging (Meyer et al., 2010). Satellite tags can provide a broader scope of movement information about tagged animals and their use of areas external to the LCMPA, whereas acoustic tagging only provides information where acoustic arrays occur, and these are most likely to be concentrated within the LCMPA. This will help identify reference sites for comparison of animal behavior both within and without the MPA. Seasonal estimates of porbeagle abundance can be determined by ensuring that data collection is performed for a duration of one or more years (>12months). Acoustic tags have a battery life of up to 10 years, opening up the opportunity to conduct evaluations of seasonal habitat use by the same individual over multiple years. Based on the literature reviewed, to look at seasonality in Porbeagles it is recommended that satellite tags be programmed to collect data over a 12 month study period, and deployed acoustic tags have a life span of a minimum of 2 years.

7.2 Black Dogfish

Understanding the benefits of LCMPA protection from human stressors for Black dogfish conservation can be greatly aided through telemetry studies. As a deep-water species, with relatively small body size, the species can only be studied in vivo using technologies like electronic telemetry. SPOT tags will be inapplicable as the species spends little to no time at the surface and their dorsal fins are too small to accommodate the tags. Although PSAT tags may enlighten Black dogfish movements, lack of ambient light and relatively restricted geographical movements likely make this technology too costly for its data output. Acoustic telemetry may be the best solution for this species. Based on trawl captures, the species is densely distributed at depths of 400 – 550 m, which suggest that receivers will need to be placed at considerable depths near the seafloor to track this species movements. Given our current understanding that the species occurs with greater abundance inside compared to outside the LCMPA boundaries, an acoustic array constructed within the protected area seems likely to provide valuable information about Black dogfish distribution and space use. Telemetry will also help to identify general patterns in movement and migration in relation to the LCMPA. Determining habitat requirements for different life stages can be informed through telemetry investigations by tagging the different life stages and monitoring the different habitats available to the animals.

Similar to for the Porbeagles, seasonality in habitat use and movements, which for black dogfish is still largely inferred, can be investigated by extending telemetry studies to ensure representation throughout all seasons. Further, another identified gap in black dogfish life history is the timing of annual pupping. Seasonal tagging expeditions could provide the opportunity to examine the proportion of YOY and juvenile individuals caught as specimens for tagging are being acquired, in addition to gathering long-term data through application of acoustic tags. Further, tagging and examination of mature females may help confirm the location of a pupping ground within shallow portions of the Laurentian Channel.

We have no evidence of post-release mortality rates for Black dogfish returned to the ocean after capture by any means. This should be taken into consideration as telemetry studies are developed. Post-handling mortality was shown to be relatively low and similar for tagged and untagged spiny dogfish (*Squalus acanthias*) released back to the wild after being caught by either trawl or gill nets (Rulifson, 2007). The spiny dogfish is a squaliform shark similar to Black dogfish in life history, size and broad distribution in the Northwest Atlantic. The methods used by Rulifson, (2007) may also be suitable or adaptable for Black dogfish research. However, undue stress may be placed on animals retrieved from considerable depths and therefore may be ill advised. Depth collection limits may be a practical solution.

7.3 Smooth Skates

The LCMPA is intended to protect Smooth Skates from human induced mortality (e.g., bycatch in the commercial fishery) in the Laurentian Channel. Being both a benthicspecies and a batoid, telemetry application for Smooth Skates will require a separate methodology than its counterparts within the Laurentian Channel, based on its size, body composition, and life style.

Tagging in skates and rays requires special consideration to avoid shedding or tag-induced mortality. Several species of skates have been tagged and followed for weeks to months using PSAT tags including Torpedo rays (*Torpedo nobiliana*; OTN, 2015) common skates (*Dipturus batis*; Wearmouth and Sims, 2009), and Thorny skates (*Amblyraja radiate*; Knotek et al., 2019). While several methods of satellite tag attachments in batoids have been used, however, it is recommended that methodology described by Knotek et al., (2019) be followed given its success for tagging Thorny skates. This species co-occurs with Smooth skates, and has a similar life history, and body size and shape (i.e., disc width), and occurs in environments similar to those found in the LCMPA (i.e., the Gulf of Maine).

Smooth skates may also benefit from acoustic tagging. Neat et al., (2015) used both acoustic and data storage (not satellite linked) tags attached externally to Flapper skates (*Dipterus cf. intermedia*) to investigate the species' movements. In this study, acoustic receivers were placed near the seafloor to monitor individual's movements for one year. Data storage tags recorded pressure and temperature. Unlike satellite data storage tags, the tags used in this study required that they be manually retrieved from re-captured individuals to offload information. Infrequent and inconsistent catches of Smooth skates may limit the utility of non-satellite data storage tags as there will be a small probability of the return of the tags and their data. Thus, passive acoustic and PSAT tagging would be the preferred approach for this species.

Habitat requirements for YOY, juvenile, and mature smooth skates are still largely unknown. The gap can be addressed using telemetry to monitor the movements of smooth skates both inside and outside the LCMPA. Acoustic receiver arrays within the LCMPA can provide detailed estimates of distribution and abundance when placed inside the LCMPA. It is also recommended that when possible, PSATs be used to determine smooth skate movements outside the boundaries of an acoustic array. Given the current knowledge of skate distribution, acoustic receivers should be placed in representative habitats for a range of life history stages. For example, the could be distributed along the contour and length of the channel slope following the design and methods applied by Daley et al., (2015). As little information is available on seasonal distributions and habitat use for this species, it is recommended that seasonal sampling occur and when possible correspond simultaneously with sampling of the other species of conservation concern within the LCMPA to reduce redundancies in research effort.

7.4 Summary Considerations

Considering the need for both long-term and fine scale monitoring over a large area of ocean space, a combined telemetric approach is recommended for LCMPA evaluation. Telemetry can help account for and avoid biases embedded within the current modes of sampling (i.e. Trawl surveys).

Acoustic tagging of priority species and associated deployments of omni-directional acoustic receivers both inside and outside the LCMPA is most relevant. Given the depth range within the LCMPA, there are several key considerations for positioning acoustic receives. Maximum depth within the LCMPA occurs within the submarine canyon at depths of around 500m. Deep-water acoustic receivers have been successfully used to monitor tagged individuals at these depths (see Loher et al., 2017 for methods). Receivers should be anchored approximately 100m from the seafloor to avoid complications related to substrate type (ie., sedimentation; Loher et al., 2017). Range testing will be essential to determine an accurate detection range and is recommended to be performed on all receivers in the array. Previous deployments of acoustic receivers (n=80) along the management division lines between 3Pn and 3Ps, and 4R and 3Pn, has helped investigate the mixing of cod stocks throughout the LC (Castonguay et al., 2004). Existing monitoring using acoustic telemetry within the St. Ann's Bank exemplifies the utility and applicability of telemetry tracking studies for monitoring MPAs (Stanley et al., 2016). A complete overlapping receiver array for the entire area of the LCMPA would require tens of thousands of acoustic receivers. In order for monitoring to remain feasible, it is recommended that a non-overlapping array be constructed within the LCMPA, with generous spacing up to 20km apart, in an evenly spaced grid format. Kraus et al., (2018) evaluated the potential of grid spacing over the entire area of Lake Erie (25,700 km^2) and showed that array scenarios with large spacing (25km) and short detection ranges (200m), using a total of 39 receivers provided greater detection resolution than selective geomorphological receiver placement. Any arrays deployed should also be compatible with existing acoustic receiver networks throughout the Northwest Atlantic for improved data collection coverage and regional information integration.

Tagging of smaller individuals is limited by individual body size and the type of tag should be considered accordingly. Tag power output and battery life corresponds to the size of the tag. For example, VEMCO (now InnovaSea) tag sizes range from their smallest V4 tag, with a length of 11 mm, and width of 3.6 mm (power output of 134 (dB re 1 uPa @ 1m), and battery life up to 62 days) to their largest V16 tag at 16mm diameter (power output up to 162 (dB re 1 uPa @ 1m), and battery life up to 10 years). Given the average sample size for acoustic and satellite elasmobranch monitoring, a minimum of 26 and 13 tags respectively are recommended for deployment on each species using either methodology. Similarly, the application and data collection of both acoustic and satellite tags should last a duration of at least one year. Considering the novel tagging procedures required for both smooth skate and black dogfish and the limited tag life of tags small enough for these species to accommodate, it may be wise to design a trial system to ensure the data collection benefits outweigh potential costs for these individuals. If individuals that have been caught are too small to tag even with the smallest available equipment, efforts should be made to gather as much information from these specimens as possible prior to release (i.e., sex and morphometric measurements like total length and fork length), provided the animals are in good physical condition at the time these are recorded.

Employing satellite telemetry using PSAT tags can further improve data collection, and therefore its use is recommended for individual elasmobranchs capable of donning such hardware. PSAT tags can provide species movement data outside of acoustic array positions, possibly leading to observations of boarder spatial and temporal patterns of these species not before observed. Combining telemetry data with additional environmental parameters or alternative species information can also provide more comprehensive insight into ecosystem dynamics and habitat preferences of all three species, thereby avoiding the pitfalls of single species monitoring outlined by Stanley et al., (2015).

Comparisons of species distributions, numbers, body size, and mortality should be made when possible using reference sites in representative habitats that are protected (within LCMPA) and compared to concomitantly monitored unprotected sites (outside LCMPA). However, Stanley et al., (2015) noted that historical fishing levels within the Laurentian Channel have been high outside, and low within the LCMPA. This likely hinders both the benefits of the protected area and the selection of suitable reference sites for comparisons. Thus, satellite data will be critical to provide data independently of reference sites. To determine tagging locations, the suggestions offered by Stanley et al., (2015) can serve as a guide for sampling sites over time. Additional considerations should also include the analysis of historical harvest in these areas (i.e., fishing effort within the MPA) in order to determine the contributions of the LCMPA, as MPAs that do little to alter the current state, rarely make effective changes (Stanley et al., 2015; Agardy et al., 2003).

8. Recommendations

The following recommendations serve as a summary of points previously discussed, and a condensed guide to support LCMPA management planning.

8.1 Species tagging methods

It is recommended that species be tagged as follows (see also Table 5): Juveniles and YOY for each species should be prioritized in order to maximize novel data collection to inform research objectives. Further, these recommendations should be considered on an individual basis and consider the health, size and body condition for each tagged individual. Capture methods may also need adjustment based on observed species mortality. Where it is recommended that telemetry be deployed opportunistically, each individual capable of supporting the given tagging technology should be tagged if the resources are available. Further, opportunistic tagging may occur only during certain research trips or times of year when data collection and resources can be capitalized on.

Table 5. Tagging recommendations for each species and respective life history stages.

Species	**Life History Stage (& size)**	**Telemetry**	**Specifics**	**Season**	**Methods**
Porbeagle	Mature Females (>217cm)	Acoustic	V16	Tagging during summer months	Longline
		PSAT, SPOT	SPOT opportunistically		
	YOY, Juveniles (<217cm (f), <174cm (m))	Acoustic	V13-V16 (size dependent)		
		PSAT	Opportunistically		

Black Dogfish	Large (>100cm)	Acoustic PSAT	V13 or smaller Opportunistically	Spring and fall tagging	By availability - trawl, longline, gillnet
	Mature (55-100cm)	Acoustic	V9-V13 or smaller		
	YOY, Juveniles (<55cm)	Acoustic	V9 or smaller		
Smooth Skates	Mature (>50 cm)	Acoustic PSAT	V9-V13 or smaller Opportunistically	Spring and fall tagging	By availability - trawl, longline, gillnet External attachment mechanisms
	Juveniles (<48cm)	Acoustic	V7-V9		
	YOY (7-10cm)	Acoustic	V7		

8.2 Acoustic receiver array within LCMPA

It is recommended that an acoustic receiver array be deployed within the LCMPA to conduct passive monitoring. Omni-directional acoustic receivers (Figure 13, represents a possible grid-spacing (20m) acoustic receiver (black dots) array for the LCMPA (purple). Generous spacing of this non-overlapping array may be supplemented with additional receiver placements to improve data collection in focal areas. For example, monitoring programs may also wish to concentrate receivers in a linear array along a portion of the shelf slope (green dots), or around zone 1a and 1b (red dots). Moreover, receiver hotspots and external references sites may be chosen based on similar habitat features or in areas that may provide additional species-based knowledge (orange dots).

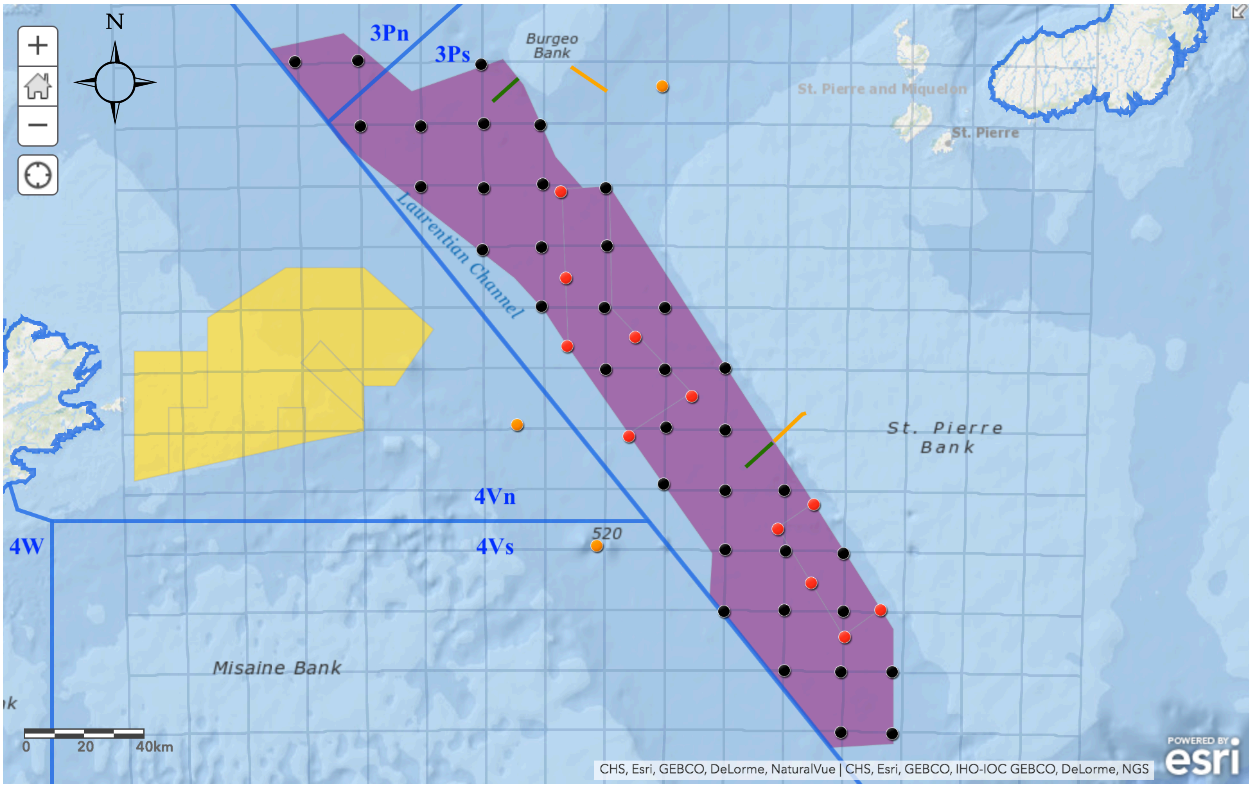

Figure 13. The LCMPA (purple polygon) and hypothetical receiver placements. Grid overlay is spaced at 20m, with black dots (n=36) representing suggested receiver placements at intersects. Red dots (n=11) provide an outline to Core Protection Zones 1a (upper) and 1b (lower), shown with white lines within the LCMPA. Green lines (n=2) show possible placements for linear receiver arrays to monitor slope areas along a depth gradient (estimates of receiver number not included). Orange dots (n=3) and lines (n=2) represent possible locations for external reference sites, following the same format as described above. Some points have been moved off grid lines to better fit the MPA shape. Note these points are not representative of habitat type or connectivity. St Ann's Bank MPA is also shown for reference, in yellow. Blue lines and labels are NAFO fisheries divisions.

8.3 Integrated monitoring and evaluation

A robust and thorough monitoring program for the LCMPA and its respective elasmobranch species will require information collected through telemetry studies to be integrated with additional knowledge collected across spatial and temporal scales. Combining data with environmental variables (i.e., temperature, primary productivity, etc.) may provide additional insight for species movement patterns and may also serve to address additional research objectives in the process.

9. Overall Conclusions

Despite the consideration of the three elasmobranch species in conservation and research objectives for the LCMPA, the effectiveness of this protected area for these species is uncertain. Telemetric investigation of these species will help determine the effectiveness of the LCMPA and inform future management. The recommendations provided are based on global examples of elasmobranch tracking in MPAs that highlight the growing need for continuous and robust monitoring. Telemetry can provide unparalleled insights into the movement patterns and core space use for species, offering information across all scales (i.e., local, regional, global) in service of better ocean conservation.

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Appendix

Table A. Checkmarks indicate the research was intended to measure that study element. Each checked element informs the overall purpose of the study. The duration of each study in number of months' data was collected was also provided. The last row shows the total number of studies that investigated each column.

Author	Movement Patterns	Diel Patterns	Seasonality	Habitat Connectivity	Site Fidelity/Resid	Sexual segregation	Duration (months)	Overall Purpose
Barnett et al., 2011	✓		✓	✓	✓	✓	12	Monitor shark movements in coastal protected areas
Barnett et al., 2012	✓				✓		24	Investigate usefulness of protected areas for sharks
Bessudo et al., 2011	✓	✓	✓	✓	✓		36	Understand scalloped hammerhead movements at protected area site and with other nearby islands
Bond et al., 2012	✓						48	Investigate use of marine reserves by Caribbean reef sharks
Brunnschweiler et al., 2010	✓	✓			✓		12	Understand adult bull shark movements
Carlisle et al., 2019	✓				✓		36	Investigate the movement of large pelagic within the large MPA
Cerutti-Pereyra et al., 2014	✓				✓		21	Describe juvenile rays space use within coastal reef environment
Chapman et al., 2005.	✓				✓		5	Understand space use of roving reef predators within the GBRMP
Chin et al., 2016	✓				✓	✓	28	Use long-term acoustic telemetry to better understand blacktip reef shark space use
da Silva et al., 2013	✓		✓		✓		24	Investigate use of MPA by smooth hound sharks
Daley et al. 2015	✓	✓	✓		✓		15	Study deep water shark movements within an MPA
Daly et al. 2015	✓						24	Investigate Tiger shark hotspots and overlap with MPAs
Dewar et al., 2008	✓		✓		✓		36	Report on factors that influence giant manta occurrence patterns
Doherty et al., 2017	✓		✓		✓		3	Assess the efficacy of a proposed MPA
Escalle et al., 2015b	✓				✓		24	Study residency and habitat preference of a small coastal shark in no-take MPA
Espinoza et al., 2015a	✓			✓	✓		24	Quantify movements and MPA use of a reef-associated species

Filous et al., 2017	✓						20	Relate the presence of human activity to the behaviour of predatory reef fish
Francis, 2013	✓				✓		4	Investigate the movements of rid within estuaries to estimate MPA impact
Garla et al. 2006	✓				✓		24	Monitor highly mobile shark species within an MPA
Garla et al., 2017	✓		✓		✓		36	Understand nurse shark movements in relation to MPA boundaries
Graham et al., 2012	✓				✓		2	Describe manta movements and occurrence within protected areas
Graham et al., 2016	✓				✓		36	Evaluate the potential protective benefits and efficacy of different spatial conservation management zones for migratory sharks
Hearn et al., 2010	✓			✓	✓		15	Demonstrate hammerhead aggregations
Heupel and Simpfendorfer, 2005	✓				✓		36	Investigate utility of long-term acoustic monitoring to evaluate shark nurseries and determine protection value of two different sized MPAs
Howey-Jordan et al., 2013	✓	✓			✓		12	Report on oceanic whitetip movements
Huveneers et al., 2006	✓	✓			✓		12	Assess Wobbegong movements using automated acoustic telemetry
Ketchum et al., 2014	✓	✓	✓	✓	✓		36	Investigate environmental influences on scalloped hammerhead movements
Knip et al., 2012a							24	Estimate mortality of two shark species within an MPA
Knip et al., 2012b	✓				✓		12	Study use of MPAs by coastal shark species
Le Port et al., 2008.	✓						5	Gain preliminary information about short tail stingray movements and develop PSAT attachment methods for stingrays
Lemahieu et al., 2017	✓		✓				12	Explore human-shark interactions
McAllister et al., 2015	✓		✓		✓		16	Examine role of area closures in highly mobile fish conservation
Meyer et al., 2010	✓		✓		✓		36	Quantify long-term movements of tiger and Galapagos sharks
Morel et al., 2013	✓		✓		✓		24	Determine fish movement patterns in a potential MPA site
Nosal et al., 2014	✓		✓		✓		36	Describe fine-scale and long-term movement patterns of leopard sharks
Oliver et al., 2019	✓				✓		2	Study thresher shark movement patterns in relation to seamounts
Papastamatiou et al., 2009	✓	✓			✓		48	Quantify movement patterns of blacktip reef sharks at a protected atoll

Papastamatiou et al., 2010	✓		✓	✓	✓		12	Study movements of blacktip reef sharks between two lagoons in a wildlife refuge
Rodríguez-Cabello & Sánchez, 2014.	✓	✓		✓			12	Investigate species movements and connectivity between deep water areas
Rodríguez-Cabello et al., 2016.	✓	✓					4	Provide more information on the diving behaviour and movements of the leafscale gulper shark
Setyawan et al., 2018	✓	✓	✓	✓	✓		24	Describe site use and movement of reef mantas in Raja Ampat
Southall et al., 2006	✓		✓	✓	✓		12	Evaluate the level of protection offered to basking sharks in European waters
Speed et al., 2012	✓				✓		12	Investigate the trophic ecology of sharks and their movement in a coastal environment
Speed et al., 2016	✓		✓		✓		36	Fill in knowledge gaps of reef shark movements in relation to spatial conservation efforts
White et al., 2017	✓				✓		9	Assess the effectiveness of large MPAs for conserving sharks
Total	**44**	**10**	**17**	**9**	**37**	**2**		**45**

Table B. Studies included for review inclusive of species, type, technology and sample size. PA = passive acoustic, AA = active acoustic, PSAT = pop-up archival, SPOT = smart position or temperature transmitting, BRUV = baited remote underwater video, SI = Stable isotopes, V = visual identification, SPLASH = satellite-linked transmitter (model specific).

Author	**Species**	**Species Type**	**Technology**	**Sample Size (n=)**
Barnett et al., 2011	Broadnose sevengill shark (*Notorynchus cepedianus*)	Deep-water	PA; PSAT	43; 5
Barnett et al., 2012	Whitetip reef sharks (*Triaenodon obesus*)	Neretic, non-migratory	PA	18
	Grey reef sharks (*Carcharhinus amblyrhynchos*)	Neretic, non-migratory	"	27
	Silvertip sharks (*Carcharhinus albimarginatus*)	Neretic, non-migratory	"	4
Bessudo et al., 2011	Scalloped hammerhead (*Sphyrna lewini*)	Neretic, non-migratory	PA	69
Bond et al., 2012	Caribbean reef shark (*Carcharhinus perezi*)	Neretic, non-migratory	PA; BRUV	34

Brunnschweiler et al., 2010	Bull sharks (*Carcharhinus leucas*)	Neretic, migratory	PSAT	20
Carlisle et al., 2019	Silky Sharks (*Carcharhinus falciformis*)	Oceanic	PSAT	2
	Grey Reef Sharks (*Carcharhinus amblyrhynchos)*	Neretic, non-migratory	PA	60
	Reef Mantas (*Manta alfredi*)	Gigantic/planktivorous	PSAT	11
	Silvertip Sharks (*Carcharhinus albimarginatus*)	Neretic, non-migratory	PSAT; PA	7; 61
Cerutti-Pereyra et al., 2014	Broad cowtail ray (*Pastinachus atrus*)	Bottom dwelling	PA	6
	Common shovel nose ray (*Glaucostegus typus*)	Bottom dwelling	"	5
	Porcupine ray (*Urogymnus asperrimu*s)	Bottom dwelling	"	4
	Reticulate or Honeycomb ray (*Himantura uarnak*).	Bottom dwelling	"	1
Chapman et al., 2005.	Nurse shark (*Ginglymostoma cirratum*)	Bottom dwelling	PA	21
	Caribbean Reef shark (*Carcharhinus perezi*)	Neretic, non-migratory	"	5
Chin et al., 2016	Black tip reef shark (*Carcharhinus melanopterus*)	Neretic, non-migratory	PA	23
Daley et al. 2015	Southern Dogfish (*Centrophorus zeehaani*)	Deep-water	PA	71
Daly et al. 105	Tiger shark (*Galeocerdo cuvier*)	Neretic, migratory	SPOT	26
da Silva et al., 2013	Smoothound shark (*Mustelus mustelus*)	Deep-water	PA	24
Dewar et al., 2008	Giant Manta (*Manta birostris*)	Gigantic/planktivorous	PA, V	41
Doherty et al., 2017	Basking shark (*Cetorhinus maximus*)	Gigantic/planktivorous	PSAT; SPOT; SPLASH	24; 23; 13
Escalle et al., 2015	Nervous shark (*Carcharhinus cautus*)	Neretic, non-migratory	PA	12
Espinoza et al., 2015a	Grey reef sharks (*Carcharhinus amblyrhynchos*)	Neretic, non-migratory	PA	36
	Silvertip (*Carcharhinus albimarginatus*)	Neretic, non-migratory	"	24
	Bull shark (*Carcharhinus leucas*)	Neretic, migratory	"	33
Filous et al., 2017	Whitetip Reef shark (*Triaenodon obesus*)	Neretic, non-migratory	PA	13

	Grey Reef shark (*Carcharhinus amblyrhynchos*)	Neretic, non-migratory	"	5
Francis, 2013	Smooth/Spotted dogfish, aka Rig (*Mustelus lenticalatus*)	Deep-water	PA	15
Garla et al. 2006	Caribbean Reef shark (*Carcharhinus perezi*)	Neretic, non-migratory	PA	14
Garla et al., 2017	Nurse shark (*Ginglymostoma cirratum*)	Bottom dwelling	PA; AA	10; 1
Graham et al., 2012	Giant Manta (*Manta birostris*)	Gigantic/planktivorous	SPOT	6
Graham et al., 2016	Bull shark (*Carcharhinus leucas*)	Neretic, migratory	SPOT	24
	Great hammerhead (*Sphyrna mokarran*)	Neretic, migratory	"	18
	Tiger sharks (*Galeocerdo cuvier*)	Neretic, migratory	"	44
Hearn et al., 2010	Scalloped Hammerhead (*Sphyrna lewini*)	Neretic, non-migratory	PA	71
Heupel and Simpfendorfer, 2005	Black tip reef shark (*Carcharhinus melanopterus*)	Neretic, non-migratory	PA	50
Howey-Jordan et al., 2013	Oceanic whitetip sharks (*Carcharhinus longimanus)*	Oceanic	PSAT	12
Huveneers et al., 2006	Wobbegong shark (*Orectolobus halei*)	Bottom dwelling	PA	7
Ketchum et al., 2014	Scalloped hammerhead (*Sphyrna lewini*)	Neretic, non-migratory	PA	134
Knip et al., 2012a	Pigeye shark (*Carcharhinus amboinensis*)	Neretic, non-migratory	PA	39
	Spottail shark (*Carcharhinus sorrah*)	Neretic, non-migratory	"	29
Knip et al., 2012b	Pigeye shark (*Carcharhinus amboinensis*)	Neretic, non-migratory	PA	37
	Spottail shark (*Carcharhinus sorrah*)	Neretic, non-migratory	"	20
Le Port et al., 2008.	Short-tailed stingray (*Dasyatis brevicaudata*)	Bottom dwelling	PSAT	2
Lemahieu et al., 2017	Bull shark (*Carcharhinus leucas*)	Neretic, migratory	PA	34
McAllister et al., 2015	School/Tope shark (*Galeorhinus galeus*)	Neretic, non-migratory	PA	40
Meyer et al., 2010	Tiger shark (*Galeocerdo cuvier*)	Neretic, migratory	PA; SPOT; PSAT	5

	Galapagos sharks (*Carcharhinus galapagensis*)	Neretic, migratory	PA; SPOT; PSAT	3
Morel et al., 2013	Small-eyed ray (*Raja microocellata*)	Bottom dwelling	PA	3
	Blonde ray (*Raja brachyura*)	Bottom dwelling	"	1
Nosal et al., 2014	Leopard shark (*Triakis semifasciata*)	Bottom dwelling	PA	33
Oliver et al., 2019	Pelagic thresher shark (*Alopias pelagicus*)	Oceanic	PA; AA	14; 10
Papastamatiou et al., 2009	Blacktip reef sharks (*Carcharhinus melanopterus*)	Neretic, non-migratory	PA; AA	9; 14
Papastamatiou et al., 2010	Blacktip reef sharks (*Carcharhinus melanopterus)*	Neretic, non-migratory	PA; SPOT; SI	49; 4; 63
Rodríguez-Cabello & Sánchez, 2014.	Leafscale gulper sharks (C*entrophorus squamosus*)	Deep-water	PSAT	5
Rodríguez-Cabello et al., 2016.	Leafscale gulper sharks (C*entrophorus squamosus*)	Deep-water	PSAT	9
Setyawan et al., 2018	Reef manta (*Mobula alfredi*)	Gigantic/planktivorous	PA	39
Southall et al., 2006	Basking shark (*Cetorhinus maximus*)	Gigantic/planktivorous	PSAT	20
Speed et al., 2012	Blacktip reef sharks (*Carcharhinus melanopterus*)	Neretic, non-migratory	PA	53
	Grey Reef shark (*Carcharhinus amblyrhunchos*)	Neretic, non-migratory	"	10
	Whitetip reef shark *(Triaenodon obesus*)	Neretic, non-migratory	"	4
	Sicklefin lemon shark (*Negaprion acutidens*).	Neretic, non-migratory	"	4
Speed et al., 2016	Sicklefin lemon shark (*Negaprion acutidens*).	Neretic, non-migratory	PA	5
	Black tip reef shark (*Carcharhinus melanopterus*)	Neretic, non-migratory	"	10
	Grey Reef shark (*Carcharhinus amblyrhuncho*s)	Neretic, non-migratory	"	10
White et al., 2017	Grey Reef sharks (*Carcharhinus amblyrhynchos*)	Neretic, non-migratory	SPOT	11

Table C. List of studies included in MPA monitoring literature review.

Author	**Location**	**MPA**	**Size (km²)**	**Restrictions**	**Habitat**	**Species**	**Conclusion**
Barnett et al., 2011	Tasmania, Australia	Shark Protected Area	176	No targeting or taking of sharks	Estuary and semi-enclosed bay	Broadnose sevengill shark (*Notorynchus cepedianus*)	Vulnerable to exploitation (less than a quarter of time spent within protected area)
Barnett et al., 2012	Coral Sea, Australia	Osprey Reef Habitat Protection Zone	195	Limited commercial fishing	Seamount	Whitetip reef sharks (*Triaenodon obesus*), Grey reef sharks (*Carcharhinus amblyrhynchos*), Silvertip sharks (*Carcharhinus albimarginatus*)	Suitable protection for these species in no-take areas
Bessudo et al., 2011	Eastern Tropical Pacific Seascape	Galapagos Marine Reserve (GMR)	138,000	No commercial fishing, limited human activity without permit, some small no-take zones,	Island coast	Scalloped hammerhead (*Sphyrna lewini*)	Local populations of hammerheads school, but do not remain within protected areas around the islands and many pregnant females were caught.
		Cocos Island National Park	1997	No-take area			
		Malpelo Flora and Fauna Sanctuary	9584	No-take fishing zones			
Bond et al., 2012	Belize	Glover's Reef Marine Park	72.76	No-take fishing zone	Barrier reef	Caribbean reef shark (*Carcharhinus perezi*)	Sharks are afforded some relief from fishing pressure within this reserve
			328.34	Multiple use zone			
Brunnschweiler et al., 2010	Walker's Cay, Abaco Islands, Bahamas	Bahamas EEZ	629,293		Island coast	Bull sharks (*Carcharhinus leucas*)	Current coastal protections are limited and should consider expansion globally
	Viti Levu, Fiji	Shark Reef Marine Reserve	3.5				
Carlisle et al., 2019	British Indian Ocean Territory (BIOT) - Chagos Archipelago	BIOT Marine Protected Area	640,000	No-take fishing zone	Archipelago	Silky Sharks (*Carcharhinus falciformis*), Grey Reef Sharks (*Carcharhinus amblyrhynchos*), Reef Mantas (*Manta alfredi*), Silvertip Sharks (*Carcharhinus albimarginatus*)	MPA is large enough to provide significant spatial protection to marine species with diverse spatial ecologies
Cerutti-Pereyra et al., 2014	Mangrove Bay, WA, Australia	Ningaloo Reef Marine Park - Mangrove Bay Sanctuary Zone	11.35	No-take in the Sanctuary Zone (covers ~33%), the larger Ningaloo Marine Park is multi-use.	Mangroves & coastal reef	Broad cowtail ray (*Pastinachus atrus*), Common shovel nose ray (*Glaucostegus typus*), Porcupine ray (*Urogymnus asperrimus*), Reticulate or Honeycomb ray (*Himantura uarnak*).	Suitable protection for juveniles encompassing the entire area used by these species for most of their time
Chapman et al., 2005.	Belize	Glover's Reef Marine Park	72.76	No-take fishing zone	Barrier reef	Nurse shark (*Ginglymostoma cirratum*)	Not large enough to protect species throughout entire range, leaving them vulnerable to exploitation.
			328.34	Multiple use zone		Caribbean Reef shark (*Carcharhinus perezi*)	

Chin et al., 2016	Cleveland Bay, QLD, Australia	Great Barrier Reef World Heritage Area (GBRWHA)	344400 (area monitored = 140)	Conservation Park Zone: no net fishing and line fishing restricted to 1 line/hook per angler Green Zone: fishing prohibited	Barrier reef	Black tip reef shark (*Carcharhinus melanopterus*)	Suitable protection for sharks that are resident within this protected zone (mostly females and juveniles)
Daley et al. 2015	Southern Australia	Fisheries Closures	1200	Closed to fishing for dogfish	Coastal	Southern Dogfish (*Centrophorus zeehaani*)	Fisheries closure is located appropriately to conserve a high proportion of the population.
Daly et al. 2018	Mozambique	Ponta do Ouro Partial Marine Reserve (PPMR)	1980 (excludes Aliwal)	Regulated commercial and recreational shark fishing	Reef	Tiger shark (*Galeocerdo cuvier*)	Tiger sharks are at high risk of interacting with fisheries and hotspots overlap minimally <6% with MPAs.
	South Africa	iSimangaliso Wetland Park (IWP)					
		Aliwal Shoal Marine Protected Area (MPA)	670				
da Silva et al., 2013	Western Cape, South Africa	Langebaan Lagoon MPA	32	No-take area	Coastal zone	Smoothound shark (*Mustelus mustelus*)	May provide adequate protection including pupping and nursery area
Dewar et al., 2008	Komodo National Park, Indonesia	Komodo Marine Park	1301.77	Restricted fishing activity	Island coast	Giant Manta (*Manta birostris*)	Provides some protection around aggregation sites where fidelity is high
Doherty et al., 2017	Scotland, UK	Sea of Hebrides Marine Protected Area	10,325	Not yet designated	Coastal zone	Basking shark (*Cetorhinus maximus*)	Provides nearly full protection in Scottish waters
Escalle et al., 2015	Mangrove Bay, WA, Australia	Ningaloo Reef Marine Park - Mangrove Bay Sanctuary Zone	11.35	No-take in the Sanctuary Zone (covers ~33%), the larger Ningaloo Marine Park is multi-use.	Mangroves & coastal reef	Nervous shark (*Carcharhinus cautus*)	Provides suitable protection and release from fishing pressure
Espinoza et al., 2015a	Great Barrier Reef, Australia	Great Barrier Reef Marine Park	344,400	Multiple Use Zones, 33% designated as no-take	Barrier reef	Grey reef sharks (*Carcharhinus amblyrhynchos*), Silvertip (*Carcharhinus albimarginatus*), Bull shark (*Carcharhinus leucas*)	Afforded some protection dependent on the species
Filous et al., 2017	Hawaii, USA	Molokini Marine Life Conservation District (MLCD)	0.31	No-take fishing area	Island coast	Whitetip Reef shark (*Triaenodon obesus*), Grey Reef shark (*Carcharhinus amblyrhynchos*)	Effective protection for sharks but not for other fish species observed
Francis, 2013	Porirua Harbour, New Zealand	Unnamed	7	Not yet designated	Estuary and semi-enclosed bay, mud flats	Smooth/Spotted dogfish, aka Rig (*Mustelus lenticalatus*)	An MPA the size of the monitored area would be effective as a protected nursery area
Garla et al. 2006	Fernando de Noronh, Brazil	Fernando de Noronha Archipelago (FEN) MPA	1829.83	No-take MPA	Archipelago	Caribbean Reef shark (*Carcharhinus perezi*)	Provides some protection for smaller sharks but would require expansion to limit vulnerablility from anthropogenic influences
				Environmental Protection Area (EPA) made for sustainable use			
Garla et al., 2017	Fernando de Noronh, Brazil	Fernando de Noronha Archipelago (FEN) MPA and Environmental Protection Area	1829.83	No-take MPA	Archipelago	Nurse shark (*Ginglymostoma cirratum*)	Unsuitable for full protection but may provide some for juveniles
				Environmental Protection Area (EPA) made for sustainable use			

Graham et al., 2012	Yucatan Peninsula, Mexico	Whale Shark Biosphere Reserve	1459.8813	Restricted use	Reef	Giant Manta (*Manta birostris*), Bull shark (*Carcharhinus leucas*)	Unsuitable and does not offer significant protection from anthropogenic activities, mainly shipping
Graham et al., 2016	Florida, USA	U.S. EEZ	1,621,632	Fishing restrictions	Coastal zone, mangrove & coastal reef, wetlands	Great hammerhead (*Sphyrna mokarran*), Tiger sharks (*Galeocerdo cuvier*)	MPA covers, at best, a small proportion of core habitat for all species and requires expansion to improve protection
	Bahamas	Bahamas EEZ	629,293	Taking any shark is prohibited			
	Florida, USA	Florida state waters	28,126	Taking Tiger and Great Hammerheads prohibited			
		Biscayne National Park (BNP), Everglades National Park (ENP) and Dry Tortugas National Park (DTNP)	7067	Fishing restrictions with limited commercial ability			
		Florida Keys National Marine Sanctuary (FKNMS)	9850	No-take and multiuse areas			
Hearn et al., 2010	Galapagos, Ecuador	Galapagos Marine Reserve	138,000	No commercial fishing, limited human activity without permit, some small no-take zones,	Archipelago	Scalloped Hammerhead (*Sphyrna lewini*)	Minimal protection
Heupel and Simpfendorfer, 2005	Tampa Bay, FL, USA	Terra Ceia Bay	MPA 1: 1.5 MPA 2: 3.5	No designation	Coastal zone	Black tip reef shark (*Carcharhinus melanopterus*)	Both reserves would provide some protection, the smaller only for juveniles
Howey-Jordan et al., 2013	Cat Island, The Bahamas	Bahamas EEZ	629,293	Taking any shark is prohibited, no pelagic long-lining	Island coast	Oceanic whitetip sharks (*Carcharhinus longimanus*)	Provides some protection
Huveneers et al., 2006	Fish Rock, NSW, Australia	Fish Rock	201	Limited fishing activity	Coastal zone	Wobbegong shark (*Orectolobus halei*)	A marine park in this area will likely provide suitable protection from fishing pressure and contribute to rebuilding species numbers
Ketchum et al., 2014	Galapagos, Ecuador	Galapagos Marine Reserve	138,000	No commercial fishing, limited human activity without permit. No-take zones	Archipelago, seamount	Scalloped hammerhead (*Sphyrna lewini*)	Offer some protection from fishing pressure
Knip et al., 2012a	Cleveland Bay, QLD, Australia	Great Barrier Reef World Heritage Area (GBRWHA)	344,400 (Conservation park zone covers 140)	Multiple Use Zones, 33% designated as no-take	Barrier reef	Pigeye shark (*Carcharhinus amboinensis*), Spottail shark (*Carcharhinus sorrah*)	Provides good protection for both species

Knip et al., 2012b	Cleveland Bay, QLD, Australia	Great Barrier Reef World Heritage Area (GBRWHA)	344,400 (Conservation park zone covers 140)	Multiple Use Zones, 33% designated as no-take	Barrier reef	Pigeye shark (*Carcharhinus amboinensis*), Spottail shark (*Carcharhinus sorrah*)	Would provide suitable protection for certain life stages
Le Port et al., 2008.	New Zealand	Poor Knights Island Marine Reserve (PKMR)	19	Restricted fishing activity	Kelp forest, rocky coastal	Short-tailed stingray (*Dasyatis brevicaudata*)	Rays do not seem to move large distances but effectiveness of protected area was inconclusive
Lemahieu et al., 2017	Reunion Island, France	Natural Marine Reserve	35	Enforced protection zone (45%): supervised nautical activity Full protection zone (5%): no human activity allowed General perimeter: multi-use	Reef	Bull shark (*Carcharhinus leucas*)	Inconclusive results about MPA effectiveness
McAllister et al., 2015	Southeast Tasmania, Australia	Shark Refuge Area (SRA)	N/A	Taking any shark is prohibited	Coastal	School/Tope shark (*Galeorhinus galeus*)	SRA provides minimal conservation given young of year and juveniles spend a considerable time outside of the SRAs.
Meyer et al., 2010	Northwestern Hawaiian Islands, Hawaii, USA	Papahanaumokuakea Marine National Monument (PMNM)	1,508,870	No-take area	Island Chain	Tiger shark (*Galeocerdo cuvier*), Galapagos sharks (*Carcharhinus galapagensis*)	Results unclear, may provide some seasonal protection
Morel et al., 2013	Portelet Bay, Jersey, Channel Islands	Portelet Bay	0.32	No designation	Kelp forest, sandy coastal	Small-eyed ray (*Raja microocellata*), Blonde ray (*Raja brachyura*)	Provides some protection but leaves rays vulnerable, needs to be larger
Nosal et al., 2014	Southern California, USA	Matlahuayl State Marine Reserve	2.69	No take, multi-use	Coastal	Leopard shark (*Triakis semifasciata*)	Provides nearly full protection but may vary with individuals
Oliver et al., 2019	Visayan Sea, Philippines	Monad Shoal - Shark and Ray Sanctuary	3.07	No-take MPA	Seamount	Pelagic thresher shark (*Alopias pelagicus*)	Provides minimal protection
Papastamatiou et al., 2009	Palmyra Atoll, HI, USA	Palmyra Atoll National Wildlife Refuge	54,126	No-take reserve	Sandy lagoon and shallow reef	Blacktip reef sharks (*Carcharhinus melanopterus*)	Inconclusive results about protection
Papastamatiou et al., 2010	Palmyra Atoll, HI, USA	Palmyra Atoll National Wildlife Refuge	54,126	No-take reserve	Sandy lagoon and shallow reef	Blacktip reef sharks (*Carcharhinus melanopterus*)	Inconclusive results about protection
Rodríguez-Cabello & Sánchez, 2014.	North Spain	El Cachucho Marine Protected Area (MPA) (aka Le Danois Bank)	2349	Restricted fishing activity	Oceanic	Leafscale gulper sharks (*Centrophorus squamosus*)	Provides limited protection due to large activity spaces
Rodríguez-Cabello et al., 2016.	North Spain	El Cachucho Marine Protected Area (MPA) (aka Le Danois Bank)	2349	Restricted fishing activity	Oceanic	Leafscale gulper sharks (*Centrophorus squamosus*)	Confirms high mobility of Leafscale gulper sharks and emphasizes continued study to understand protection benefits
Setyawan et al., 2018	Raja Ampat, West Papua, Indonesia	Raja Ampat MPA	9100	Sharks and rays are protected	Archipelago	Reef manta (*Mobula alfredi*)	Protected area covered some but not all areas where mantas showed high site fidelity offering incomplete protection

Southall et al., 2006	European Continental shelf	British Territorial Waters	1498864	No directed catch for basking sharks although fishing is allowed	Coastal zone	Basking shark (*Cetorhinus maximus*)	Does not provide adequate protection and needs to be expanded
Speed et al., 2012	Coral Bay, WA, Australia	Ningaloo Reef Marine Park - Coral Bay	21.51	No-take area	Reef	Blacktip reef sharks (*Carcharhinus melanopterus*), Grey Reef shark (*Carcharhinus amblyrhunchos*), Whitetip reef shark (*Triaenodon obesus*), Sicklefin lemon shark (*Negaprion acutidens*).	Conclude that good protected areas can be small as long as they limit harmful activities
Speed et al., 2016	Mangrove Bay, WA, Australia	Ningaloo Reef Marine Park - Mangrove Bay Sanctuary Zone	883.65	Multi-use, Commercial fishing prohibited	Reef	Sicklefin lemon shark (*Negaprion acutidens*), Black tip reef shark (*Carcharhinus melanopterus*), Grey Reef shark (*Carcharhinus amblyrhunchos*)	Provides minimal protection given the area is too small and site fidelity of adults is low
White et al., 2017	Palmyra Atoll, HI, USA	Palmyra Atoll National Wildlife Refuge	54,126	No-take reserve	Island coast	Grey Reef sharks (*Carcharhinus amblyrhynchos*)	Provides substantial but incomplete protection