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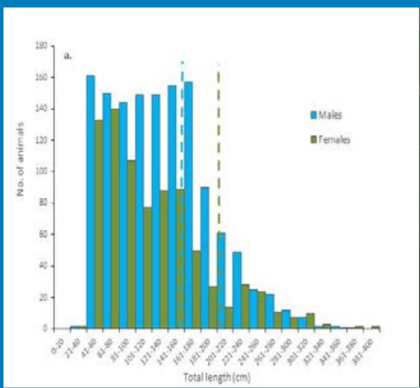

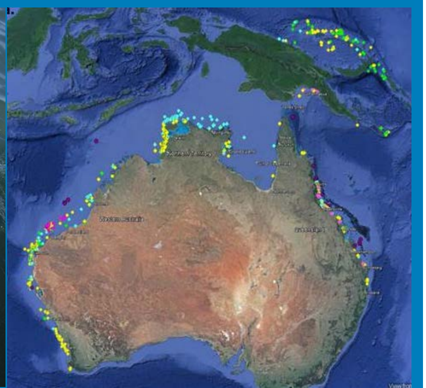

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PROJECT SUMMARY

Hammerhead sharks are the focus of conservation management in Australian waters as the result of recent listing on CITES and CMS. However, the state of knowledge of hammerhead sharks in Australia requires further exploration. Data on hammerhead interactions with fisheries, life history and ecology have been gathered to address this need. Data revealed significant gaps in areas sampled and limited understanding of the dynamics of species presence/distribution relative to habitat features or environmental conditions. Use of different habitats by different sex or size groups makes refining the distribution and abundance of hammerhead species difficult. Collected data were used to construct a series of conceptual models of population structure of hammerhead sharks in Australia and adjacent countries. This exercise revealed an urgent need to define connectivity of hammerhead shark populations within and beyond Australia to ensure management can be applied at the appropriate scope and scale.

1. BACKGROUND

Hammerhead sharks are iconic and widely recognised based on their unique hammer-shaped head shape. Despite their wide recognition and distinction from other sharks, individual hammerhead species can be difficult to differentiate and are often recorded simply as “hammerhead” in catch records. The lack of distinction between species has led to limited or confused data on the status and trends of hammerhead populations worldwide (e.g., Hayes et al 2009; CITES 2013; Koopman and Knuckey 2014). In addition, the various hammerhead species occupy different ecological niches despite their overlapping distributions. Differences in ecological niche space do not allow generalisations to be made across species. Four hammerhead species occur in Australian waters, 3 tropical and 1 temperate species.

The Smooth Hammerhead, *Sphyrna zygaena* is widespread in temperate southern Australia, extending into tropical regions on both the east and west coast of Australia. This species occurs over the shelf in waters to at least 60 m deep (Last and Stevens 2009) and is currently assessed as Vulnerable globally on the IUCN Red List (Casper et al. 2005). The current IUCN Oceania regional assessment for *S. zygaena* is Least Concern indicating populations are not significantly threatened as evidenced by stable catch rates in Western Australia (Simpfendorfer 2014). Although *S. zygaena* is distributed to tropical regions on both coasts of Australia, overlap with tropical species is limited. Data regarding this species in tropical regions is limited though and future research should be conducted to determine if *S. zygaena* is present in the tropics but using different habitats to other hammerhead species. The remaining three hammerhead species have overlapping ranges in northern Australian waters. The Winghead Shark (*Eusphyra blochii*), Great Hammerhead (*Sphyrna mokarran*), and Scalloped Hammerhead (*Sphyrna lewini*) are all found in northern Australia from WA to NSW (Last and Stevens 2009). All three species are found on the continental shelf to varying depths, including shallow inshore waters (Last and Stevens 2009). In addition to their occurrence on the continental shelf *S. zygaena* and *S. lewini* all occur in open ocean habitats at some stages of their life. Hammerhead distributions are also confounded by the tendency of these species to aggregate in specific regions and/or segregate based on size or sex (Last and Stevens 2009; CITES 2013) and their ability to travel large distances (Diemer et al. 2011; CITES 2013). These behavioural patterns have made it difficult to define population or stock boundaries, and hence the identification of management units on which to base conservation management remain unclear.

Based on IUCN Red List assessments *E. blochii* is currently considered to be Near Threatened globally (Simpfendorfer 2003) and Least Concern in Australian waters. However, it is worth noting this species is fairly uncommon and not well studied. In contrast, *S. mokarran* and *S. lewini* are more commonly encountered and considered at greater risk of extinction than the other two species. Both *S. mokarran* and *S. lewini* are assessed as globally Endangered (Baum et al. 2007, Denham et al. 2007) and Vulnerable and Endangered in Oceania, respectively. In addition to these IUCN Red List assessments indicating the threatened status of hammerhead sharks, recent listing on the Convention on the Conservation of Migratory Species (CMS) and the Convention on International Trade in Endangered Species (CITES) have highlighted global concerns over the status of these species. Current CMS and CITES listings are based primarily on the status of *S. lewini* as the best known and studied of the hammerhead species. Listing of *S. mokarran* and *S. zygaena* on these conventions has been as lookalike species to *S. lewini* (CITES 2013). Listing lookalike species was implemented as a precaution to strengthen protection for *S. lewini*, as such all three species are currently listed on Appendix II of CITES and *S. lewini* and *S. mokarran* are listed on Appendix II of CMS. Listing on CMS Appendix II results in automatic protections under the EPBC Act to render the species no-take. The Australian Government chose to take a reservation on participation in the CMS listing to avoid unnecessary prosecution of fishers who incidentally catch these species. Listing on CITES Appendix II requires regulation and reporting of trade in listed species. Australia has completed a Non Detriment Finding (NDF) to demonstrate that current levels of take in Australian waters are sustainable and will not cause hammerhead sharks to become threatened. Despite this finding, the three *Sphyrna* species are currently under assessment for potential listing under the EPBC Act. In addition, in NSW *S. lewini* is currently listed as Endangered and *S. mokarran* is listed as Vulnerable. These global, national and state listing processes indicate that accurate data on the status and trends of hammerhead sharks in Australian waters are urgently needed and would be highly relevant to management and conservation decisions made at all levels of government.

2. AIMS

Recent CMS and CITES listings of hammerhead sharks, and nomination of these species for listing under the EPBC Act, make them a high priority for research, conservation and management. This project examines the current state of knowledge on hammerhead sharks in Australia waters to define what is currently known and identify data and knowledge gaps. The objectives of this project were to:

- Provide a synopsis of knowledge of *S. lewini* and *S. mokarran* in Australian waters;
- Produce conceptual models of the stock structure of hammerhead shark species caught in Australian fisheries, current data supporting these models and a plan for defining stock structure;
- Provide a preliminary status assessment of hammerhead populations and identification of key knowledge gaps and research priorities.

3. APPROACH

Review and assimilation of existing data was conducted to help define the status of hammerhead sharks within Australian waters. Analysis focused on tropical hammerheads because they were considered to be in the highest threat categories. The separate distribution and lower conservation concern for *S. zygaena* made it a lower research, management and conservation priority than the other three species. Due to the somewhat rarity of *E. blochii* data are limited for this species, as such the majority of this analysis focuses on *S. mokarran* and *S. lewini*.

Information on hammerhead catches and fishing effort in Australian waters was recently compiled and analysed by Koopman and Knuckey (2014). That study examined data from all State, Territory and Commonwealth fisheries relative to five CITES listed species (*Carcharhinus longimanus, Sphyrna lewini, Sphyrna mokarran, Sphyrna zygaena* and *Lamna nasus*). The current report will summarise the relevant findings of that earlier work rather than repeat such a recent and thorough analysis. While the work of Koopman and Knuckey (2014) examined fisheries data of hammerhead species broadly, Simpfendorfer (2014), in summarising available data for the production of the NDFs, identified that the known size and sex segregating behaviour of hammerhead sharks made the interpretation of these data difficult. In particular, the relationship with stocks in Indonesia might have significant consequences for how decline data should be interpreted. As such, the current project sought to gather data to help understand the complexities of the organisation of hammerhead shark species in northern Australia and adjacent nations to better inform decision making on conservation and management by the Australian Government.

Data from multiple sources were gathered and integrated to define the distribution, size and sex classes of hammerhead species. Based on the northern Australian focus of this assessment data sets were sourced primarily from this region. Assembled data included: baited remote underwater video sampling (Australian Institute of Marine Science), fishery-independent and/or observer sampling (James Cook University, Western Australian Fisheries, Northern Territory Fisheries) and directed fishery and market sampling in Indonesia and Papua New Guinea (CSIRO). This combined data set covered sampling in Queensland, Northern Territory, Western Australia, Indonesia and Papua New Guinea. These data were plotted spatially to define areas of occurrence and patterns in size and sex distributions in the data sets. Size and maturity data used to assess individuals in sample data sets were taken from Last and Stevens (2009), White et al. (2008) and Harry et al. (2009) as appropriate.

Finally, distribution, size and sex data, along with existing data on genetic stock structure (e.g. Ovenden et al. 2009) were used to construct a series of conceptual models of possible stock structures of *S. lewini* in the Australian region. These models represented a set of testable hypotheses that would help to inform assessments and define stock boundaries for management actions.

4. RESULTS

Fisheries review

The recent assessment by Koopman and Knuckey (2014) revealed that Australian fisheries comprise 8.5% of the reported global catch of hammerhead sharks based on catches from 2001–2011. Four main fisheries are responsible for the majority (90%) of hammerhead shark harvest in Australia: The Northern Territory Offshore Net and Line Fishery (ONLF), Queensland East Coast Inshore Finfish Fishery (ECIFF), Western Australian Northern Shark Fishery (NSF) and Western Australian Temperate Demersal Gillnet and Demersal Longline Fishery (TDGDLF) (Figure 1). Australian catch varied from 200–600 t during this period with declines evident since 2004. However, it is unclear if declines are based on population declines or changes in fisheries practise and/or altered management. Declines in catches reflect changes in effort in some areas, but may reflect population decline in others. For example, Heupel and McAuley (2007) reported declines in hammerhead catch per unit effort in WA's northwest. There catch rates fell from 0.18-0.19 kg/hook in the late 1990s to between 0.05 and 0.11 kg/hook until 2005/2006 (Figure 2). Regional risk assessments also indicated hammerhead species may be at high risk when considering combined effort of north coast targeted shark fisheries. Defining the actual status and declines of hammerhead species is complicated by fishery variation and management intervention as well as species identification issues. With three species sharing an overlapping distribution it is difficult to know which species is being captured and how that relates to status and decline. Koopman and Knuckey's analysis of catch and disaggregation of unspecified hammerhead catch indicates that *S. lewini* forms the majority of the catch in Australian waters (Figure 3). Koopman and Knuckey (2014) suggested that management arrangements need to be refined to improve information collection to more accurately define the status of Australian hammerhead populations. Understanding Illegal, Unreported and Unregulated (IUU) catch and species level catch reporting in log books are two priorities for helping improve our understanding of these species.

In addition to directed fisheries take as explored by Koopman and Knuckey, other extractive practices are in place that can affect hammerhead shark populations. Studies by Stevens (1984), de Faria (2012) and Cheshire et al. (2013) have revealed hammerhead sharks are captured and retained by recreational fishers. de Faria (2012) reported that up to 7% of recreational shark catch in Queensland is comprised of hammerhead sharks. Shark control programs are also a source of mortality for hammerhead sharks. Although the species composition of this catch is not well known, hundreds of hammerheads of various sizes have been captured in shark control nets in recent years (Noriega et al. 2011; Reid et al. 2011). Analysis of time series shark control program catch in northern Queensland indicated that hammerhead catch rates had declined to between 16.5% and 33.4% of original levels by the early 1990s (Simpfendorfer et al. 2011), although not all of this decline may have been the result of the shark control program as fisheries in the region also take hammerhead sharks (Harry et al. 2011a). Noriega et al. (2011) also reviewed Qld shark control program catch of scalloped hammerheads and revealed a decline in female total length over a 10 year period. It is unclear what has caused this change in size composition, but it could reflect a change in population structure over time. Stock depletion, environmental change or reduced prey abundance were all suggested as possible reasons for the change in size structure. Noriega et al. (2011) also state that this change in size structure might present implications for the future management and recovery of hammerhead shark populations because litter sizes have been linked with female size (i.e., larger females produce more young per litter). Reduced size in females may result in smaller litters and slower population increase or recovery. Thus, understanding the dynamics of hammerhead shark populations, size and sex characteristics in each region is crucial to an accurate understanding of population dynamics and subsequent management measures. In an assessment of the status of hammerhead sharks relative to producing an Australian NDF for CITES, Simpfendorfer (2014) suggested that national catch limits should be initiated and that connectivity between Australian and neighbouring country (e.g. Indonesia, Papua New Guinea) populations should be explored as a priority to define fisheries interactions and population status. Consideration of the size and sex of individuals in the catch is also likely warranted.

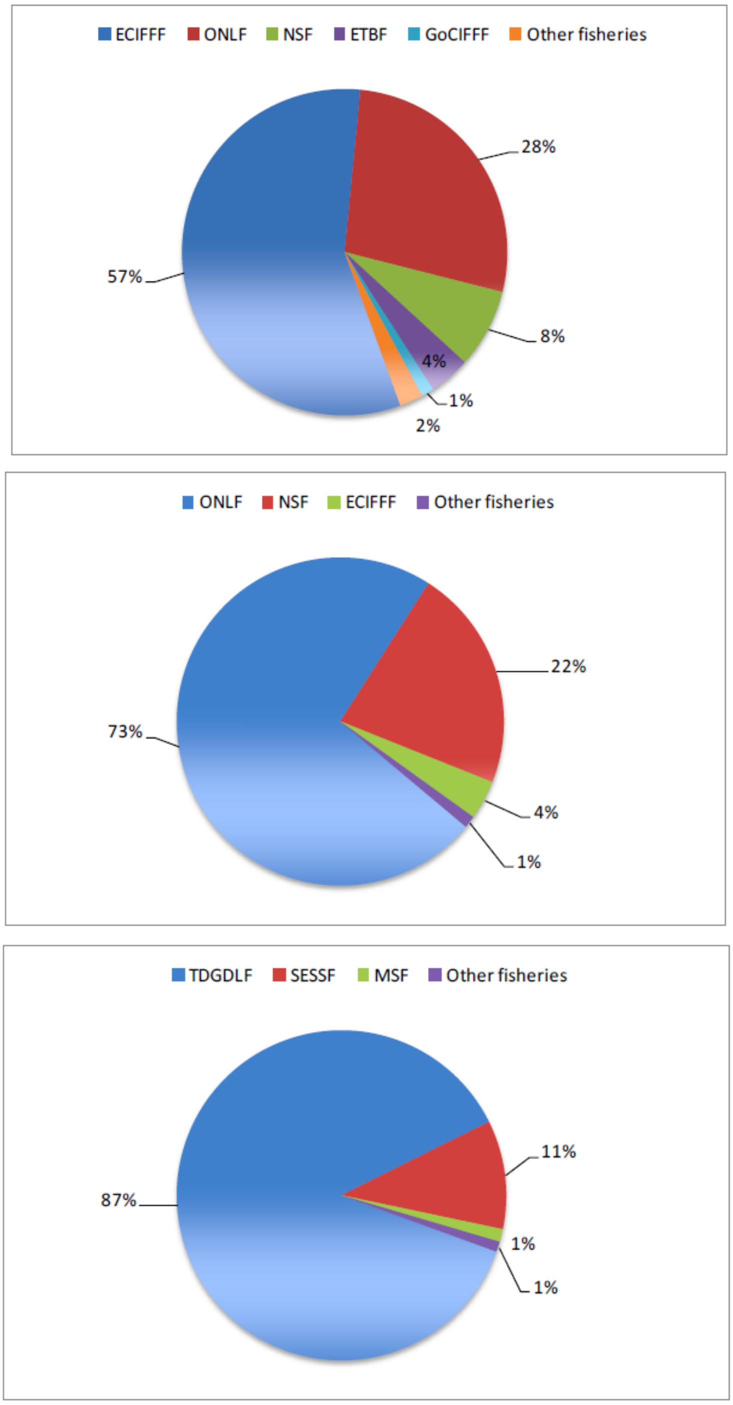

Figure 1. Fishery catch of *S. lewini*, *S. mokarran*, and *S. zygaena* (from top to bottom) extracted from Koopman and Knuckey (2014). Fishery abbreviations: ECIFF = East Coast Inshore Finfish Fishery (Qld), ONLF = Offshore Net and Line Fishery (NT), NSF = Northern Shark Fishery (WA), ETBF = Eastern Tuna and Billfish Fishery (Commonwealth), GoCIFF = Gulf of Carpentaria Inshore Finfish Fishery (Qld), TDGDLF = Temperate Demersal Gillnet and Demersal Longline Fishery (WA), SESSF = Southern and Eastern Scalefish and Shark Fishery (Commonwealth), MSF = Marine Scalefish Fishery (SA).

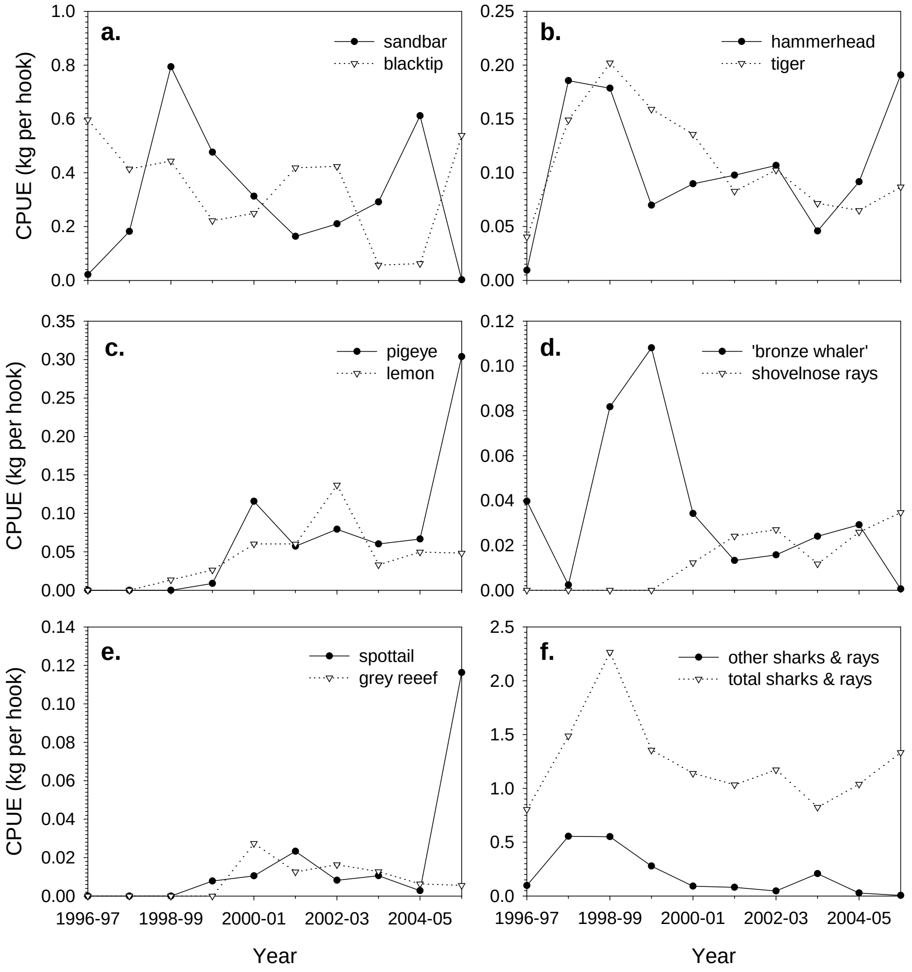

Figure 2. Ten year time series of shark catch (CPUE) from northwestern Australia, extracted from Heupel and McAuley (2007). Hammerhead catch is shown in panel b.

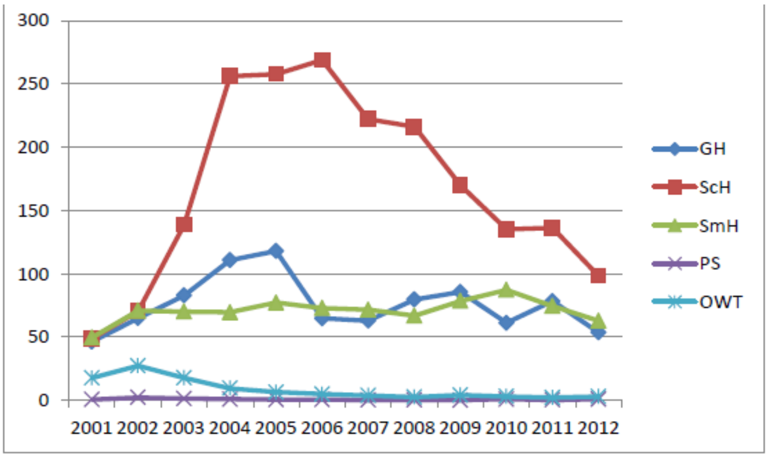

Figure 3. Total catch of CITES listed sharks in Australia indicating *S. lewini* (scalloped hammerhead) has the largest take. Extracted from Koopman and Knuckey (2014).

5. IDENTIFICATION ISSUES

As indicated in fishery statistics, identification of tropical hammerhead species can be difficult. There are two opportunities to physically identify hammerhead species: at the time of capture as whole specimens and after initial processing as products (fins and trunks). When processed beyond these points genetic analysis is the only reliable way to currently determine the species. Identification at the time of capture provides the best opportunity to clearly differentiate the species. Separating *E. blochii*, the winghead, from the other two species is relatively simple when viewing a whole animal (Figure 4c). In contrast, *S. lewini* (Figure 4a) and *S. mokarran* (Figure 4b) are similar in appearance and can be difficult to differentiate.

Figure 4. Images of scalloped (*S. lewini*), great (*S. mokarran*) and winghead (*E. blochii*) after fishery capture from top to bottom. Images supplied by W. White.

Once captured and processed by fishers it is even more difficult to determine the identity of a species. For example, individuals are gutted and the fins and head removed. At that stage the trunks (bodies) will look identical and difficult to separate even from other shark species. The fins may be distinctly “hammerhead” due to their taller height than most other sharks, but they are difficult to separate between species (see Figure 5). Difficulty in identifying individuals and their products make management and enforcement of catch and trade difficult, and is one of the primary reasons for applying lookalike provisions to hammerheads in international protections. This complexity should be considered in relation to the three tropical hammerhead species found in northern Australia to ensure adequate management and traceability of product can be applied.

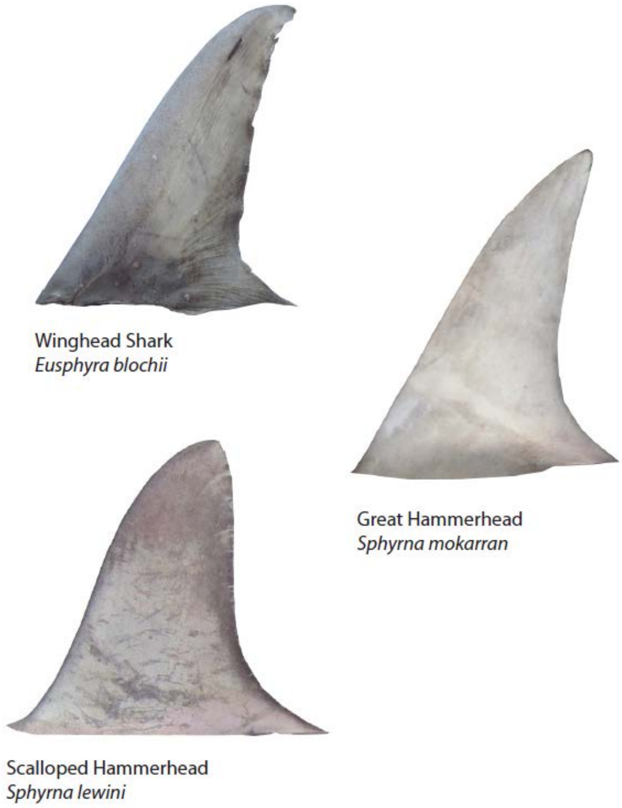

Figure 5. Dorsal fins from three hammerhead shark species after removal by fishers. Note the similarities in height and fin shape which distinguish these species from other sharks, but make species identification within the group difficult. Images provided by W. White.

6. LIFE HISTORY

The life history of elasmobranchs often varies geographically (Clarke et al. 2015) which creates a need for region specific data. All hammerhead species have been studied to some extent in Australian waters, but the amount and quality of the data is variable. For some species certain biological parameters can only be sourced from overseas populations.

The winghead, *E. blochii*, is the least common and thus least well-studied of the Australian hammerheads. Based on a small number of samples Smart et al (2013) estimated the life span of *E. blochii* to be at least 20 years. It is born at 45-47 cm and reaches a maximum length of 186 cm (Stevens and Lyle 1989) making it the smallest of the hammerhead species that occur in tropical Australia. This species is viviparous and produces litters of 6-25 young after a 10-11 month gestation period. Young are often born in February and March in Australia (Stevens and Lyle 1989) and anecdotal data suggest a patchy distribution in northern Australia with reasonable numbers encountered in some regions and a lack of individuals in others. Wingheads are most commonly encountered in shallow waters on continental and insular shelfs suggesting high susceptibility to inshore gillnet fisheries where present.

Scalloped and great hammerhead sharks captured by commercial fishers on the east coast of Australia (QLD) were recently used to define region specific life history characteristics for these two species (Harry et al. 2011b). Scalloped hammerhead (*S. lewini*) catch was dominated by males (324 male, 195 female) and also biased toward juveniles. Age and growth studies of *S. lewini* revealed a size of birth at 45-50 cm and maximum lengths of at least 301 cm for males and 346 cm for females (Stevens and Lyle 1989). Since no females of maximum size were sampled by Harry et al. maximum age could not be estimated, but males were estimated to live to at least 21 years. The oldest female aged (260 cm) was 15 years. In contrast, great hammerheads (*S. mokarran*) were less prevalent, but sex ratio in the catch was more even (65 male, 77 female). Sampled *S. mokarran* included larger individuals (369 cm male, 439 cm female) which allowed maximum ages to be estimated for both sexes: 31.7 (male) and 39.1 (female) years. Reproductive patterns of these two species are similar to *E. blochii* although litter sizes vary with *S. lewini* producing 13-41 young per litter and *S. mokarran* ranging from 6-33 young per litter (Stevens and Lyle 1989). These regional findings reflect the known pattern of long life spans and low fecundity typical of sharks.

Both *S. lewini* and *S. mokarran* are found in continental and insular shelf habitats, as well as oceanic habitats. However, the complex patterns of distribution within these species complicate our understanding of population dynamics. For example, Harry et al. (2011b) suggested young are born inshore and remain in shallow (<25 m) habitats for long periods (years). Males appear to remain inshore for as many as 10 years while females appear to leave these habitats after approximately three years, indicating sex based differences in habitat use. This suggests large juvenile and adult females reside in different habitats. Likewise, adult males are largely absent from coastal regions.

Genetic studies of *S. lewini* have revealed divergent patterns of movement between males and females, reflecting the sexual segregation often apparent in populations from catch data. For example, female genetic markers suggest limited movement and limited stock structure over large spatial scales (Duncan et al. 2006). In the Oceania region, Ovenden et al. (2009, 2011) found no evidence of stock separation between Australian and Indonesia. However, it has been suggested that recent advances in genetic approaches may be able to detect population separation not previously possible.

7. DISTRIBUTION

Scalloped and Great Hammerheads

Species distributions as observed in the analysed data reflected the known distributions of the species (Figure 6) with *S. lewini* and *S. mokarran* distributed across the northern tropics of Australia. Interestingly, the distribution varied when data from Papua New Guinea (PNG) were added. Only two *S. mokarran* were recorded in the PNG data set despite large numbers of *S. lewini* observed. This result suggests there are likely some subtle differences in the movement and distribution patterns of these two species.

Examination of the broad-scale data by sex and size class revealed differences among categories and across species (Figure 7). Adult female hammerheads showed the greatest variation with low numbers of *S. lewini* present in most regions. Encounters with *S. mokarran* appeared to be more common, particularly in northern Australia, but absent from PNG. This result is likely the result of the sampling approach in PNG which is focused offshore. If inshore sampling was conducted higher numbers of *S. mokarran* may be encountered. Adult males appeared to be similarly distributed between the two species, as were neonates and juveniles which appeared to use inshore regions most heavily, thus increasing their encounter rate with gillnet fisheries and increased reporting of their presence.

Figure 8 displays the size frequency of individuals captured in all of the analysed Australian data sets. It is apparent from this assessment that the majority of *S. lewini* catch in Australia is juveniles, with the majority of female *S. lewini* catch below size at sexual maturity. Although some mature males were recorded, the majority of the male catch is also small. This suggests that adults are residing in regions not exploited by the sampled fisheries. This could indicate distribution in more offshore habitats such as sea mounts, or use of adjacent regions in the Pacific Ocean and Coral Triangle. The size distribution of *S. mokarran* was larger than for *S. lewini* indicating broader exploitation of all size and age classes, but numbers in the data set were lower. This could reflect lower numbers of *S. mokarran* in the region or a broader distribution. Given the nature of inshore fisheries (dominated by gillnet) and the propensity of hammerheads for capture in net gear it is unlikely that *S. mokarran* is present and undetected.

The distribution of the national data is a reflection of the location of research and sampling efforts. For example, there are few if any data available from Torres Strait and the Gulf of Carpentaria. It is likely that there are large numbers of hammerheads in these regions. Likewise, exploration of shelf edge and seamount habitats may reveal aggregations of hammerheads as occur in other parts of their distribution (Klimley and Nelson 1981). Sampling in PNG suggests that offshore habitats provide suitable habitat for adult and juvenile *S. lewini*. For example, Gulf of Papua regions less than 30 m deep are important habitat for juveniles. It is possible some of the missing size and age groups occur in these less explored regions of the Australian EEZ.

8. REGIONAL DISTRIBUTIONS

Western Australia

Examination of regional patterns revealed subtle differences in distribution not apparent in the broad-scale analysis. Comparison of *S. lewini* and *S. mokarran* distributions in WA (Figures 9 and 10) reveal similar distributions for adult male and female sharks. Males and females also appear to be present in the same or similar areas suggesting sexual segregation is not observed in aggregated data, or sexes are missing in these areas at some points in time. Distribution of immature individuals varied with *S. lewini* appearing to occur further south along the WA coast (Figure 9), while neonates were only encountered in northern parts of the state. Immature *S. mokarran* were not as evident further south and no neonate individuals were reported, suggested they may be present in different habitats than neonate *S. lewini*.

Size frequency of individuals in the Western Australian catch showed distinct differences between species, but catch ratios of male and female individuals were similar (Figure 11). Like the national analysis, *S. lewini* were predominantly small immature individuals while *S. mokarran* were mainly larger with fewer immature individuals encountered. This may suggest slight differences in habitat use among species in WA where smaller *S. mokarran* are using different habitats, possibly offshore. This pattern has previously been reported in sandbar sharks in WA where adults are found nearshore and juveniles are known to use offshore regions (McAuley et al. 2007). A similar pattern may occur with *S. mokarran*, but this requires further exploration.

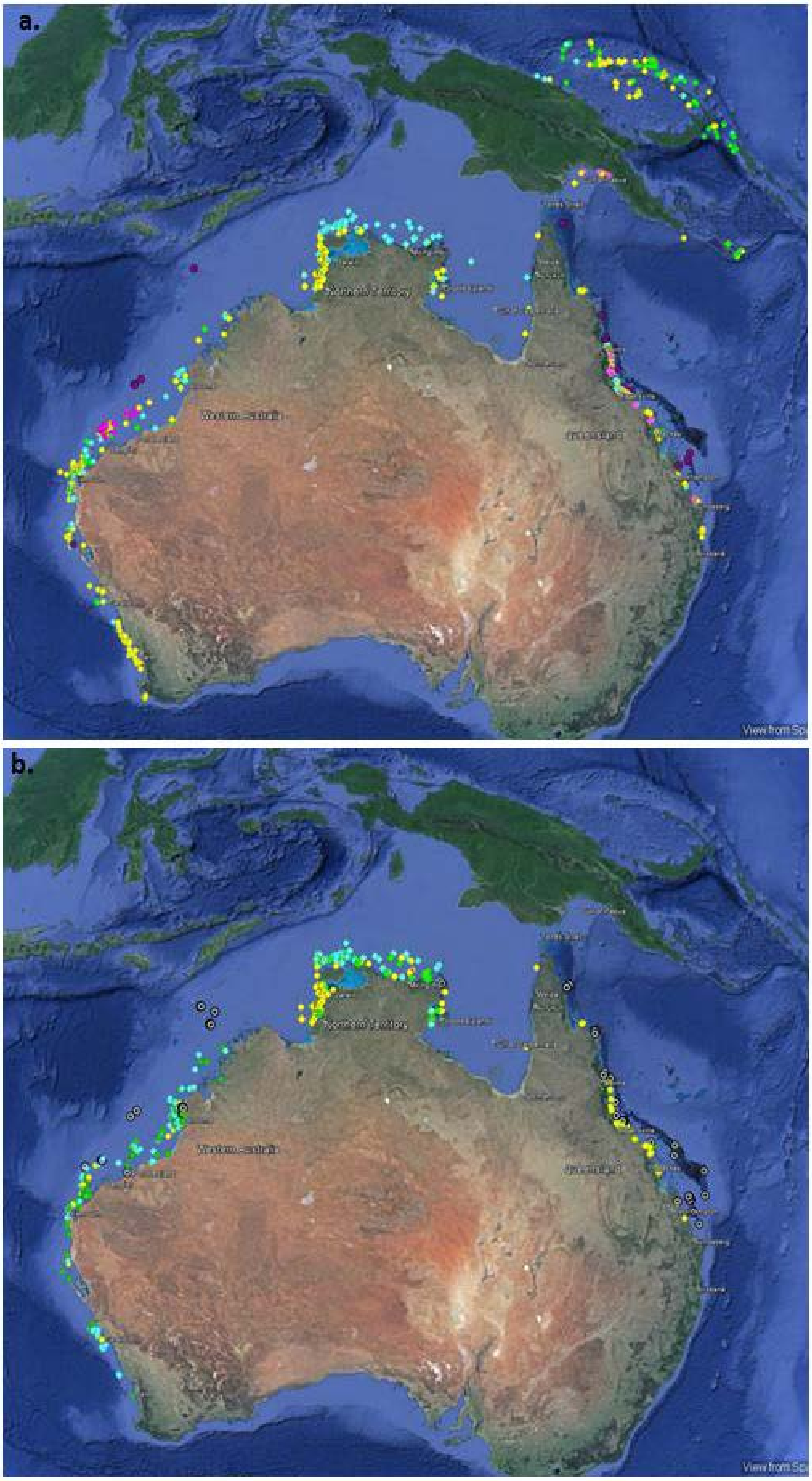

Figure 6. Location data used to define the distribution of hammerhead sharks for: a) *S. lewini* and b) *S. mokarran*. Map data ©2015 Google

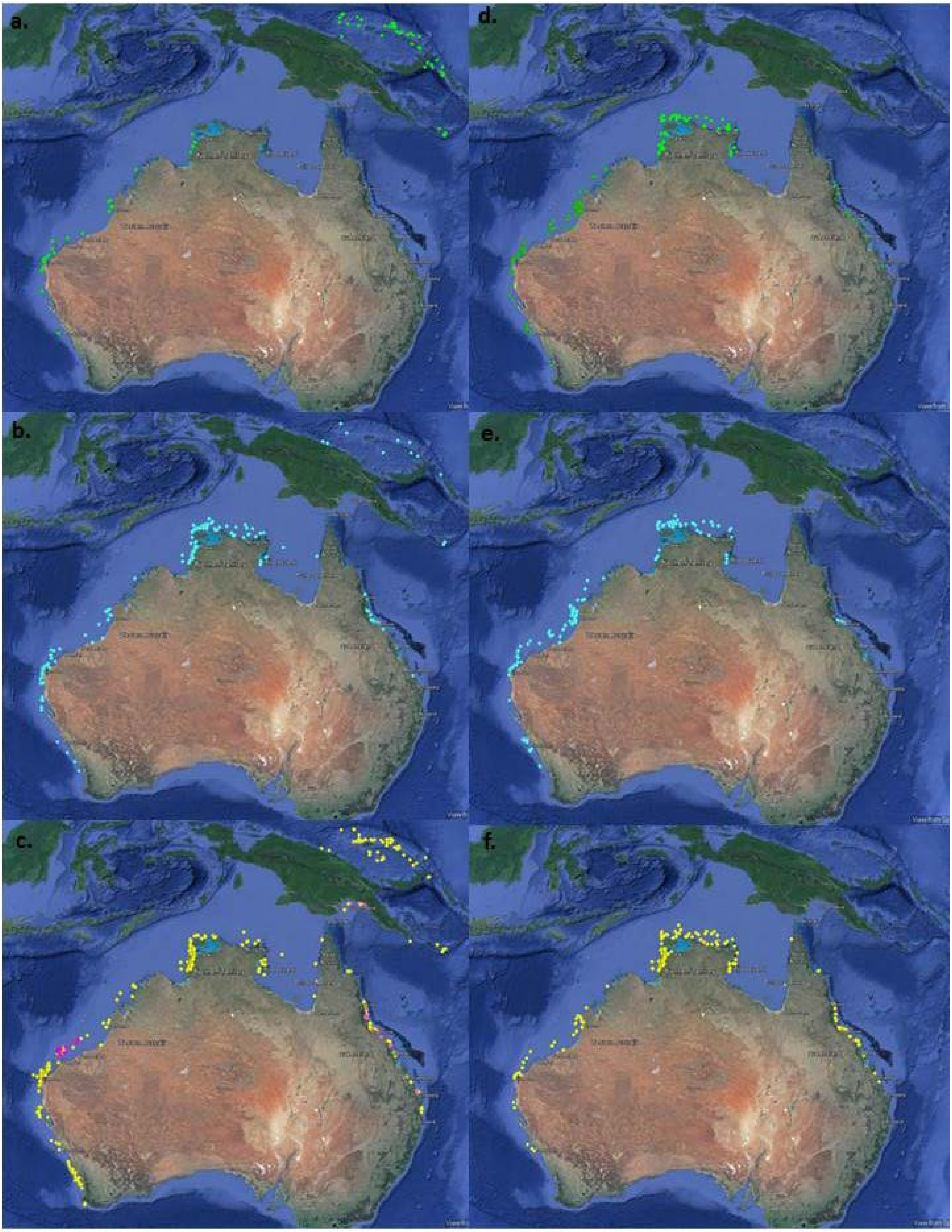

Figure 7. Distribution of: a-c) scalloped hammerhed (*S. lewini*) and d-f) great hammerhed sharks (*S. mokarran*) for the different sex and size categories: a, d) adult females, b, e) adult males, c, f) immature and neonate individuals of both sexes. Map data ©2015 Google

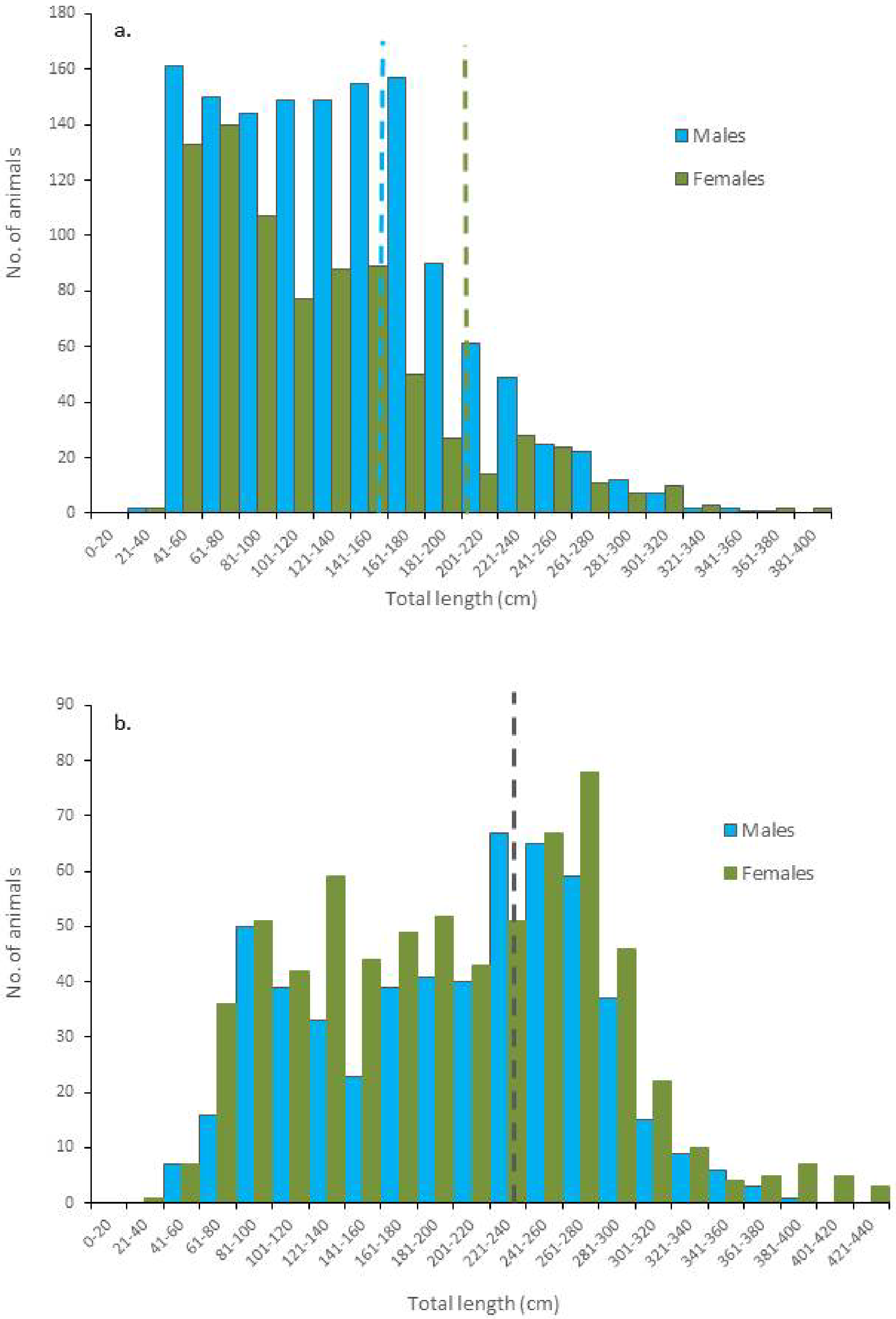

Figure 8. Size frequency a) *S. lewini* and b) *S. mokarran* in Australian waters by sex. Dashed lines represent corresponding size at maturity for each sex and species.

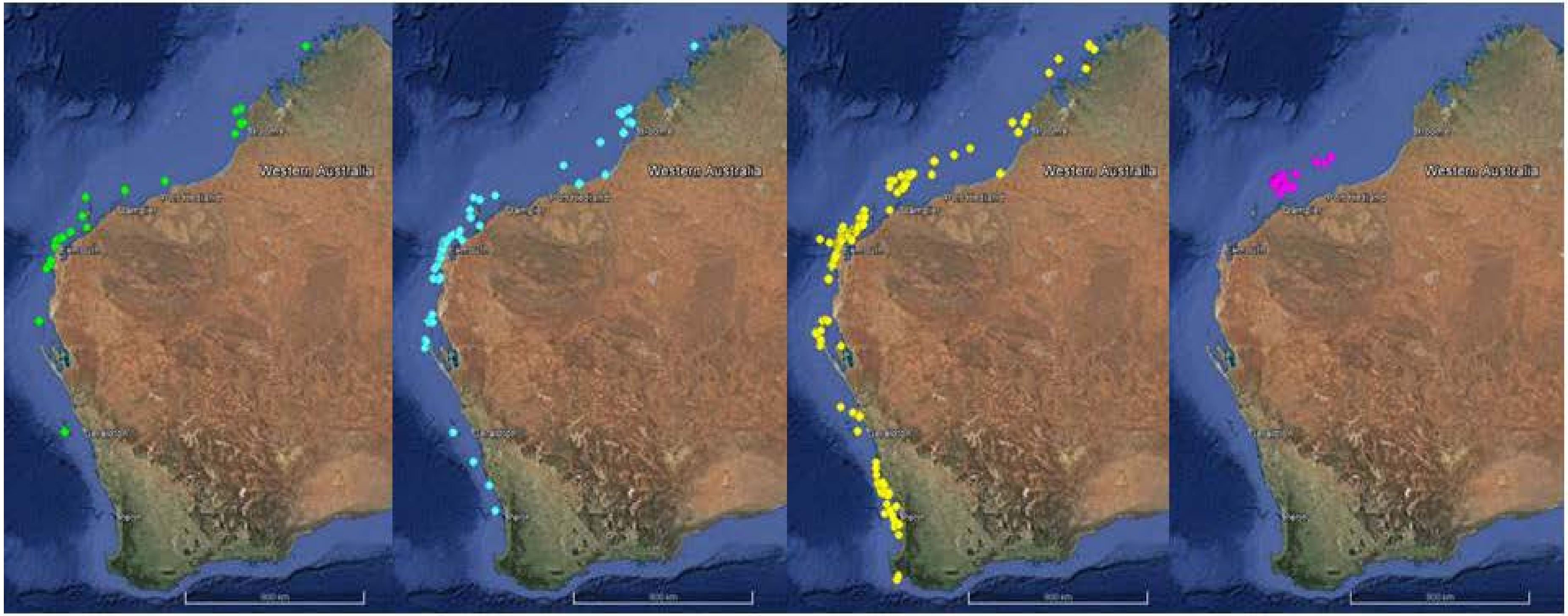

Figure 9. Distribution of scalloped hammerhed sharks (*S. lewini*) in Western Australia where green indicates adult females, blue indicates adult males, yellow and pink indicate immature and neonate individuals of both sexes respectively. Map data ©2015 Google

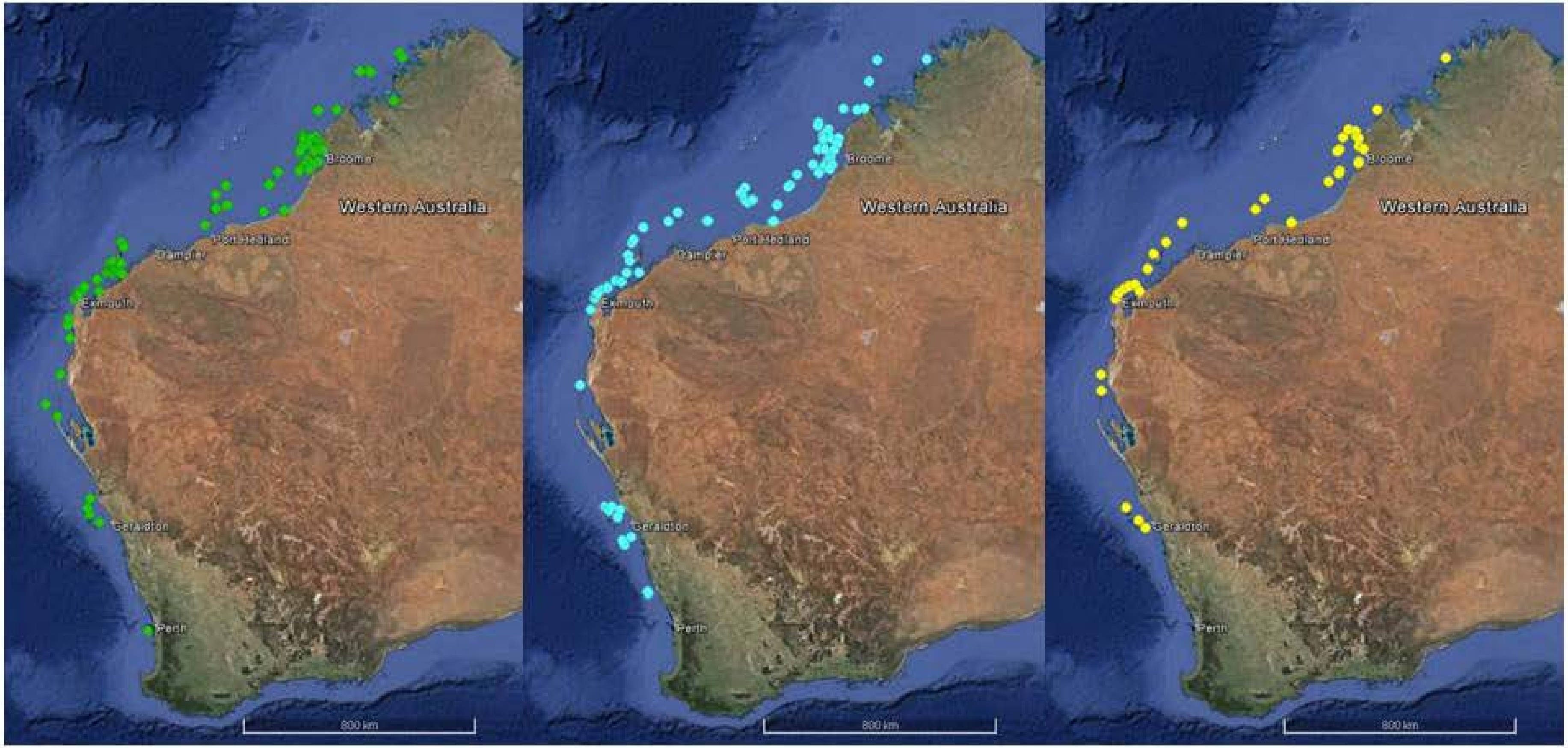

Figure 10. Distribution of great hammerhed sharks (*S. mokarran*) in Western Australia where green indicates adult females, blue indicates adult males, yellow indicates immature individuals of both sexes. Map data ©2015 Google

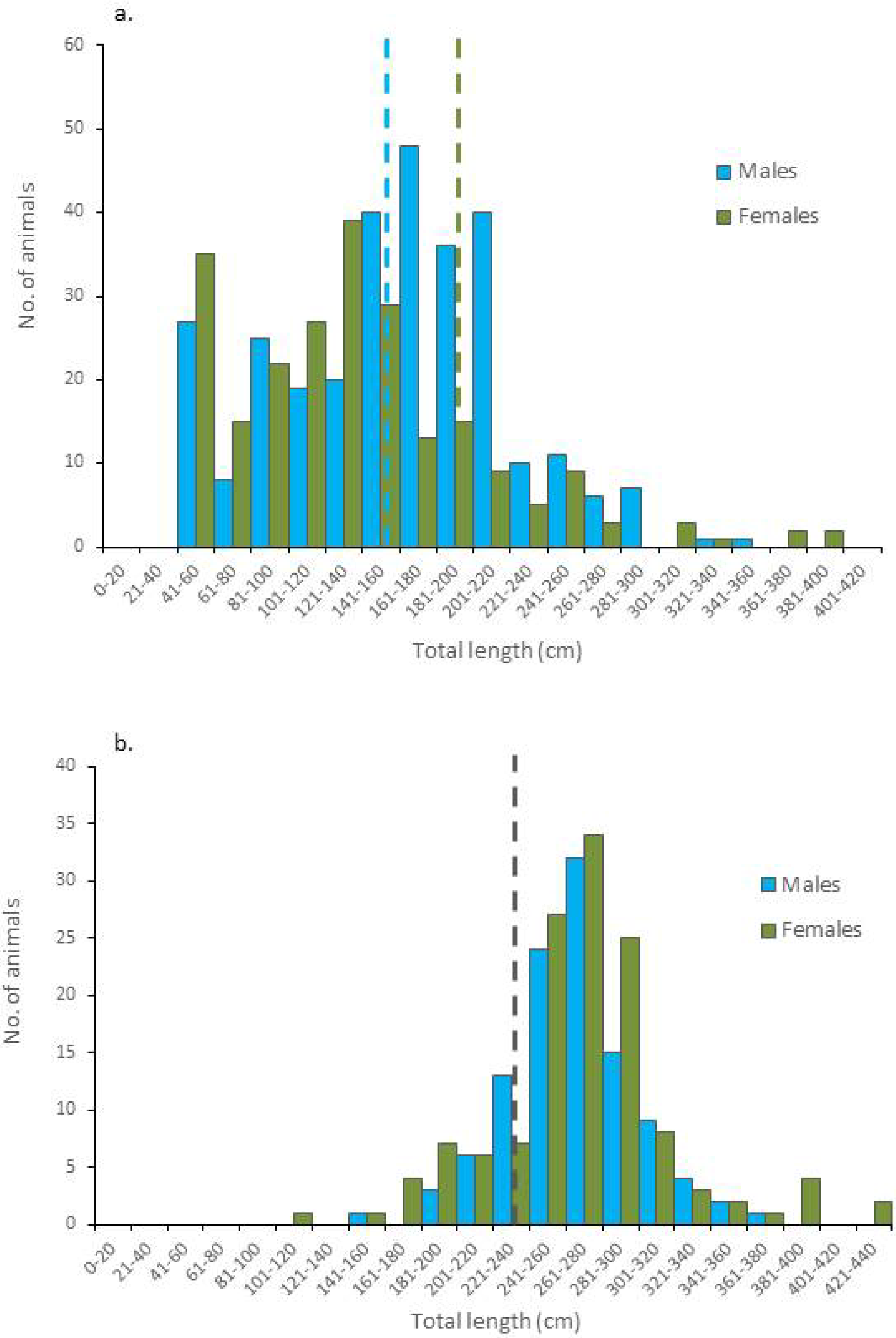

Figure 11. Size frequency of individuals encountered in Western Australia by sex for a) *S. lewini* and b) *S. mokarran*. Dashed lines represent corresponding size at maturity for each sex and species.

Northern Territory

Data from NT revealed few female adult *S. lewini* (Figure 12), which contrasted with both male *S. lewini* and female *S. mokarran* data (Figures 12 & 13). Adult female *S. lewini* were limited in their area of capture, although there was overlap with areas of high immature shark catch suggesting some use of similar habitats. Adult males were more widely distributed. Distribution of *S. mokarran* was similar to that of male and immature *S. lewini* for all size and sex classes. In contrast to findings in WA, however, a small number of neonate *S. mokarran* were encountered in nearshore regions. Heavy distribution of both species in nearshore habitats is most likely a reflection of sampling and fishery activity than an indication of habitat preferences.

Size structure of NT hammerheads varied from the patterns observed in WA. In NT catch of *S. lewini* was dominated by males ranging in size from juveniles to mature adults, although largest male size classes were not encountered (Figure 14). Most female *S. lewini* were juveniles below 140 cm in length. In contrast, *S. mokarran* were captured in lower numbers, but over a much broader size range. Male and female individuals were encountered at similar rates and all but the largest size classes were present. These results differ from the size distributions encountered in WA and may reflect habitat differences between the two regions or other unknown variables might be driving this pattern. Differences in sampling location may also play a role since WA sampling included offshore regions not represented in the NT data.

Queensland

Sampling distribution in Qld revealed limited sampling in far north regions and the Gulf of Carpentaria. Thus, hammerhead encounter data were more prevalent in central and southern portions of the state. The Qld data is the only set that did not encounter any adult female *S. lewini*. This sets these data apart from other Australian regions (Figure 15). Adult males, immature individuals and neonates appeared to be present over a large portion of the state, particularly in coastal regions where sampling was most prevalent. In contrast to *S. lewini*, adult female *S. mokarran* were reported in a number of locations along the coast (Figure 16). Adult males, however, were restricted to a small section of the Qld coast. It is unclear if this is the result of a restricted distribution, or if other factors such as sampling effort, time of year, etc may have contributed to this result. Like NT, immature individuals in Qld were found nearshore. Although hammerhead sharks are known to be present on the Great Barrier Reef (GBR), fishery data to define the rate of encounter is limited. Heupel et al. (2009) reported 'hammerhead' as a minor component of reef line fisheries in the GBR. Therefore the extent of hammerhead shark distribution in the GBR and outer shelf habitats are largely unknown. Similar to NT, the Qld data were biased toward nearshore regions leaving offshore habitats less well studied.

Size frequency data from Qld revealed large numbers of immature *S. lewini* of both sexes and few individuals of either sex over 140 cm (Figure 17). This strongly suggests differences in habitat use by size or age classes. Data for *S. mokarran* were similarly biased to smaller size classes.

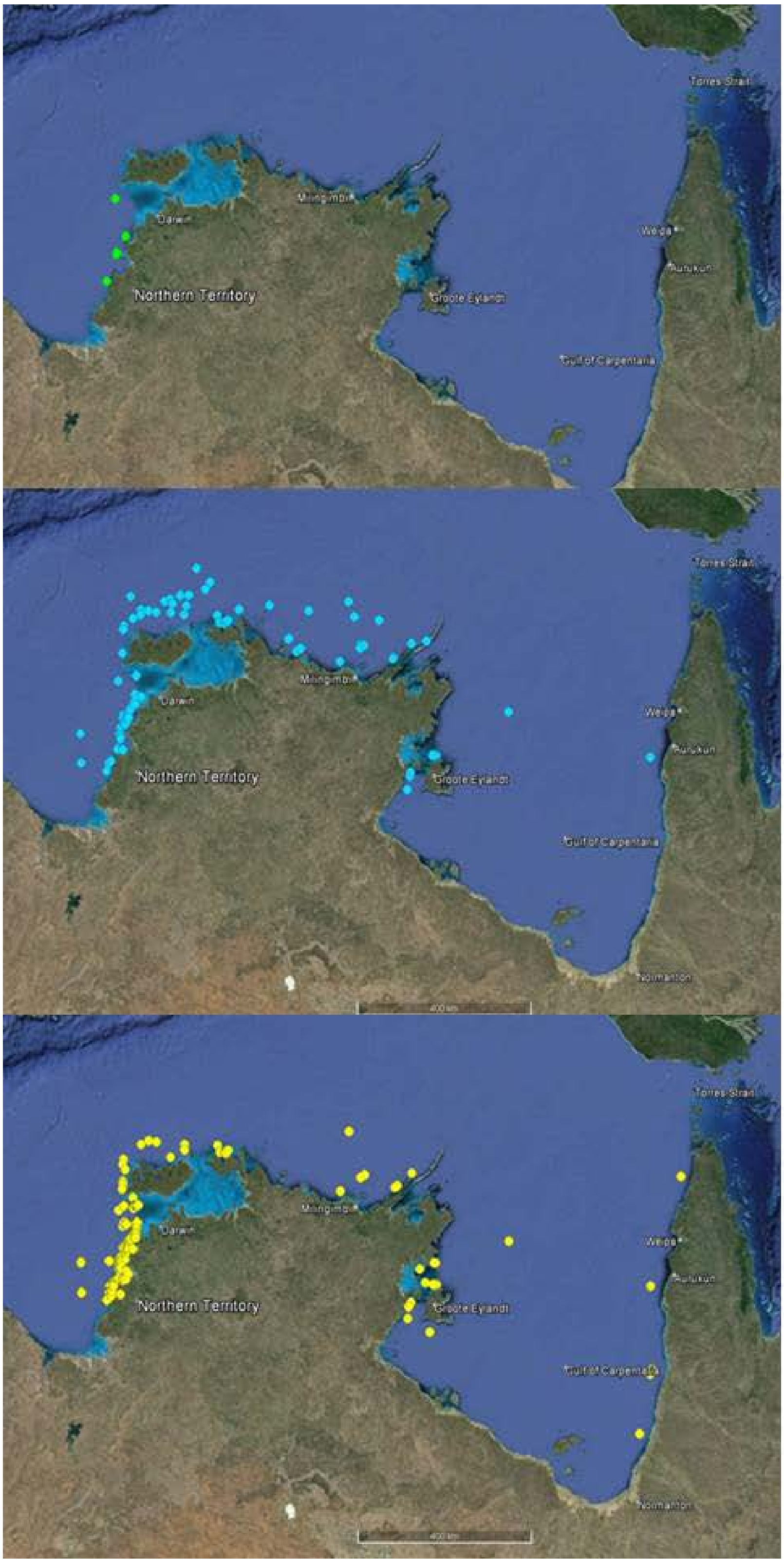

Figure 12. Distribution of scalloped hammerhed sharks (*S. lewini*) in Northtern Territory where green indicates adult females, blue indicates adult males, yellow and pink indicate immature and neonate individuals of both sexes. Map data ©2015 Google

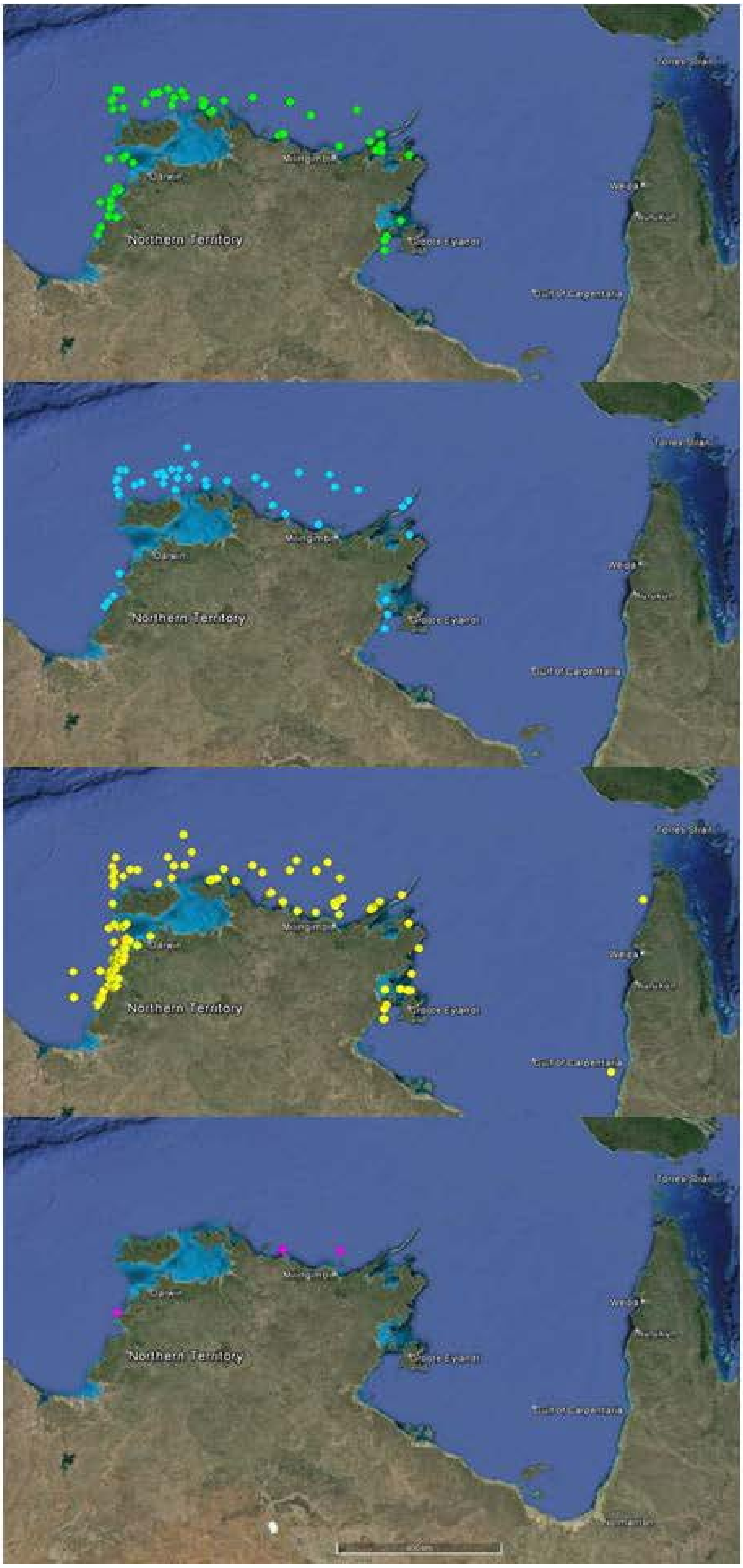

Figure 13. Distribution of great hammerhed sharks (*S. mokarran*) in Northern Territory where green indicates adult females, blue indicates adult males, yellow indicates immature individuals of both sexes.
Map data ©2015 Google

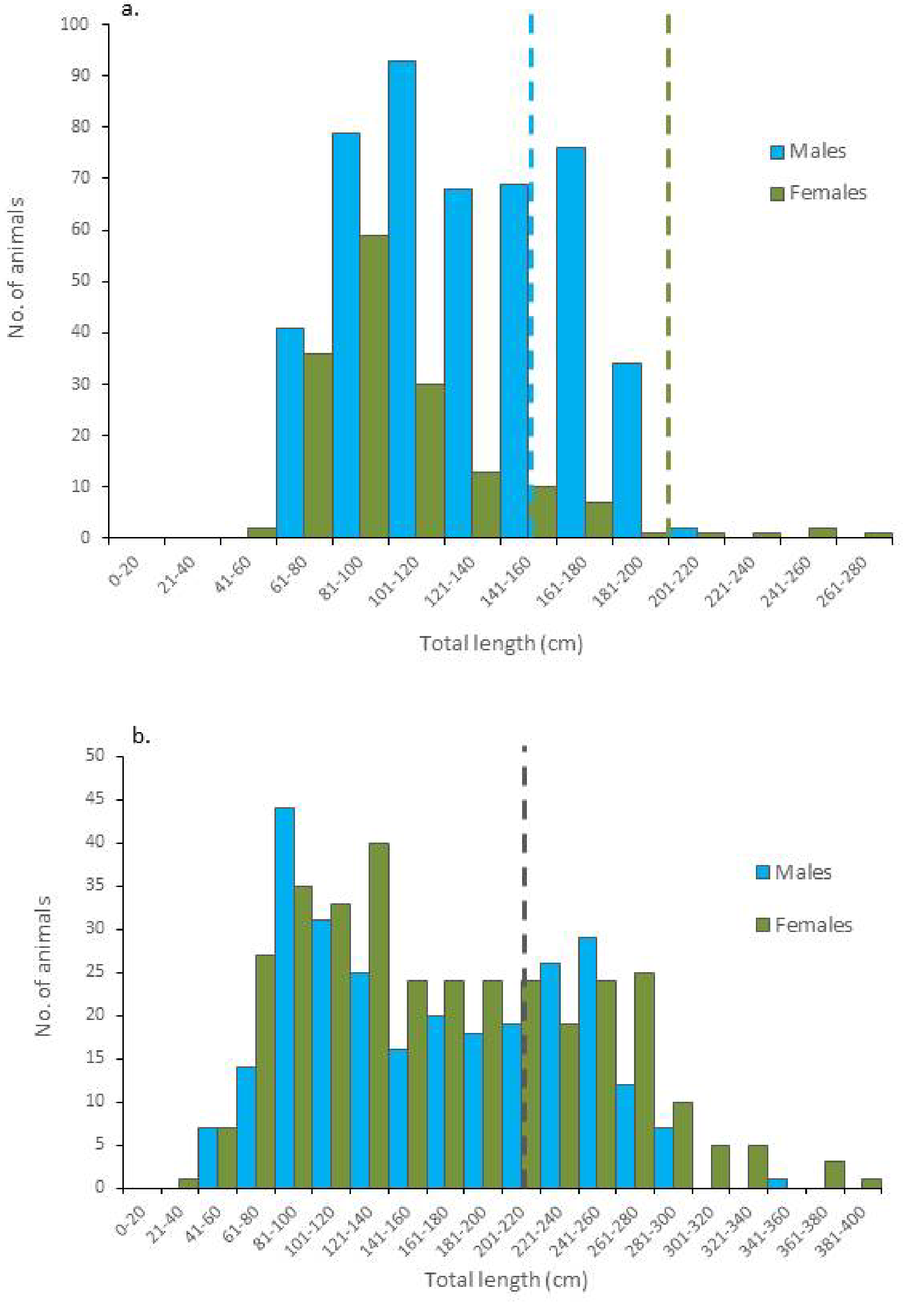

Figure 14. Size frequency of individuals encountered in Northern Territory by sex for a) *S. lewini* and b) *S. mokarran*. Dashed lines represent corresponding size at maturity for each sex and species.

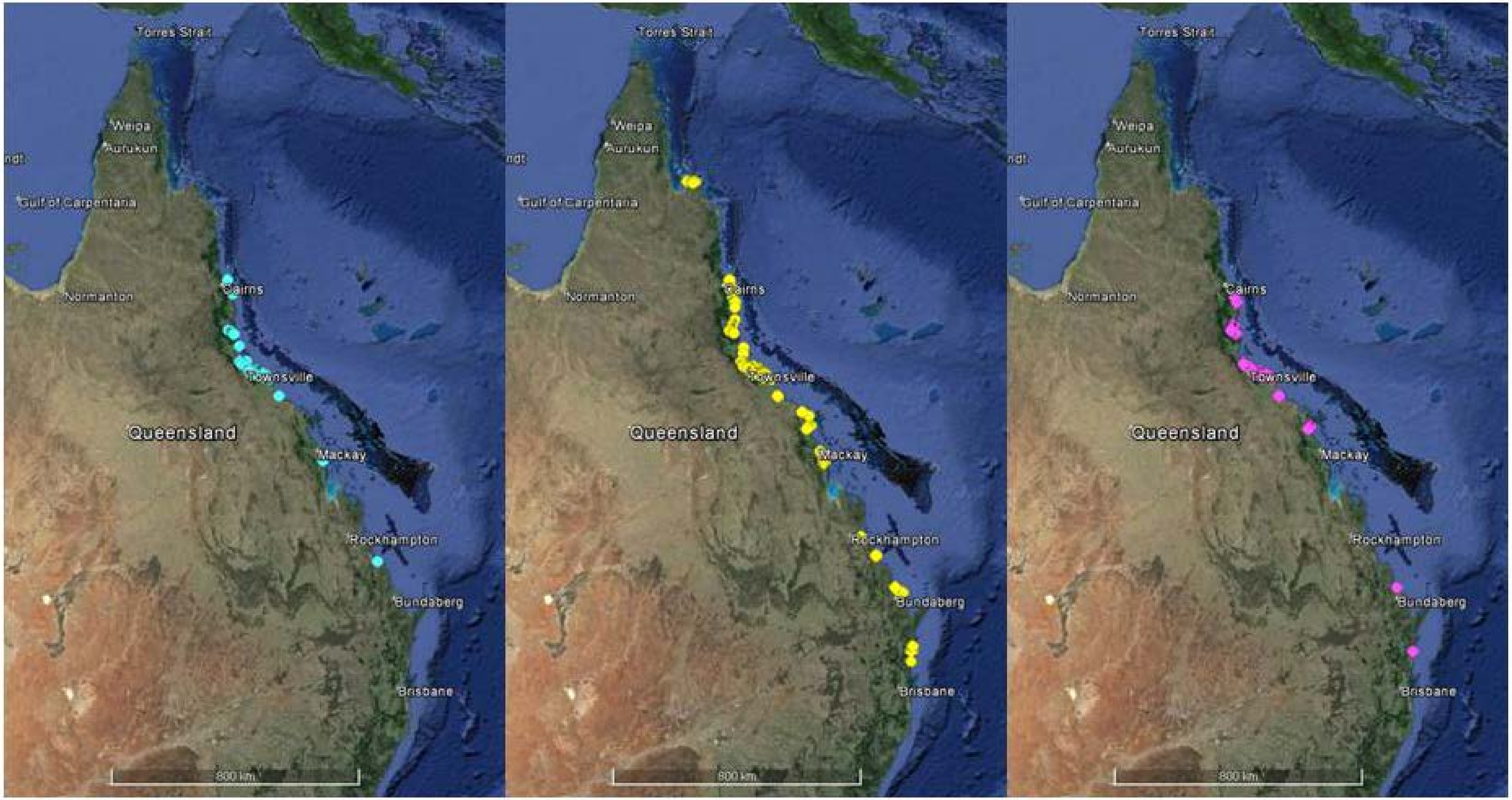

Figure 15. Distribution of scalloped hammerhed sharks (*S. lewini*) in Queensland where blue indicates adult males, yellow and pink indicate immature and neonate individuals of both sexes. Note no adult females were present in the data set. Map data ©2015 Google

Figure 16. Distribution of great hammerhed sharks (*S. mokarran*) in Queensland where green indicates adult females, blue indicates adult males, yellow indicates immature individuals of both sexes. Map data ©2015 Google

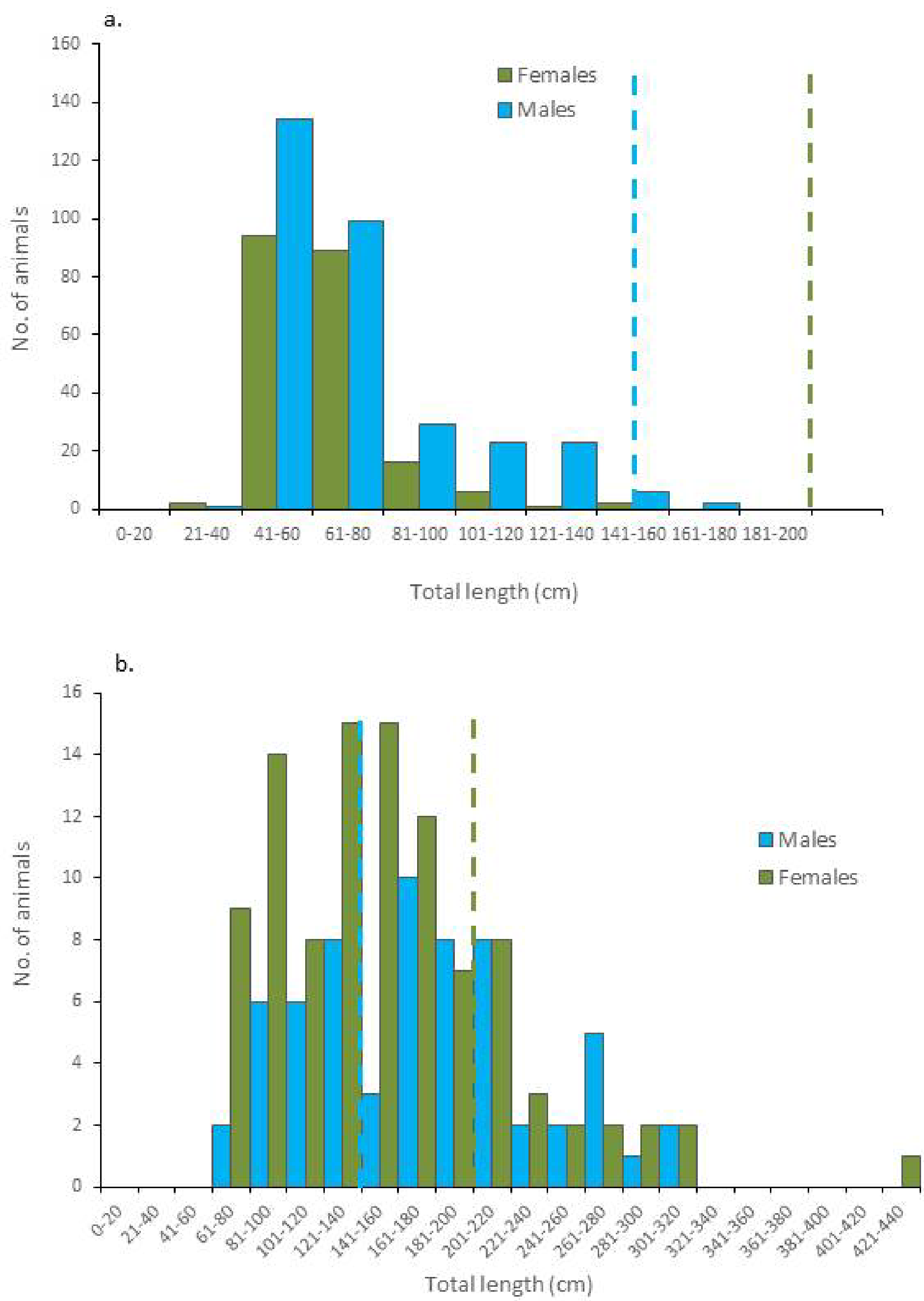

Figure 17. Size frequency of individuals encountered in Queensland by sex for a) *S. lewini* and b) *S. mokarran*. Dashed lines represent corresponding size at maturity for each sex and species.

Papua New Guinea

Data from PNG reveal a starkly different pattern to that observed in Australian waters. Firstly, only two *S. mokarran* were encountered. As indicated previously, this is likely a reflection of fishing efforts and data collection focused on offshore regions. Higher levels of inshore sampling may reveal a different pattern. The area of sampling in PNG also covered much different habitat to that targeted in Australia with much of the sampling occurring on oceanic ridge habitat (Figure 18). Analysis of the catch data revealed adult females and immature individuals were prevalent in ridge habitats which may provide some clues as to preferred habitat for Australian populations. Few adult males were encountered, however, suggesting sexual segregation is prominent. It is unclear whether the lack of males in PNG and higher numbers in Qld is indicative of a shared stock, or whether more complex distribution patterns and habitat use are occurring. Immature and neonate individuals were also recorded from inshore regions indicating similar patterns of pupping in shallow coastal regions also occur in PNG habitats. Size frequency data from PNG varies dramatically from that observed in Australia with a female dominated sample, at least some of which were reproductively mature (Figure 19). Although mature males were encountered, they tended to be low in number.

Indonesia

Samples from Indonesia were collected from markets post-landing and as such distribution of catch was not available, although were from southern Indonesian waters. Hammerheads are encountered in multiple markets suggesting distribution throughout the region. Composition of the catch reflected that of PNG where few *S. mokarran* were observed (Figure 20). Like PNG, it is difficult to define why so few individuals were encountered, but given that all habitats are heavily fished in Indonesia, overexploitation of the stocks is highly likely. The limited number of *S. mokarran* observed mean that the vast majority of hammerhead catch in Indonesian waters is comprised of *S. lewini*. Size and sex frequency of *S. lewini* from Indonesia reveals low numbers of males, like PNG, and a female dominated catch including large adults. The catch of *S. lewini* in PNG and Indonesia appear to cover a broader size range than sampling in Australian waters.

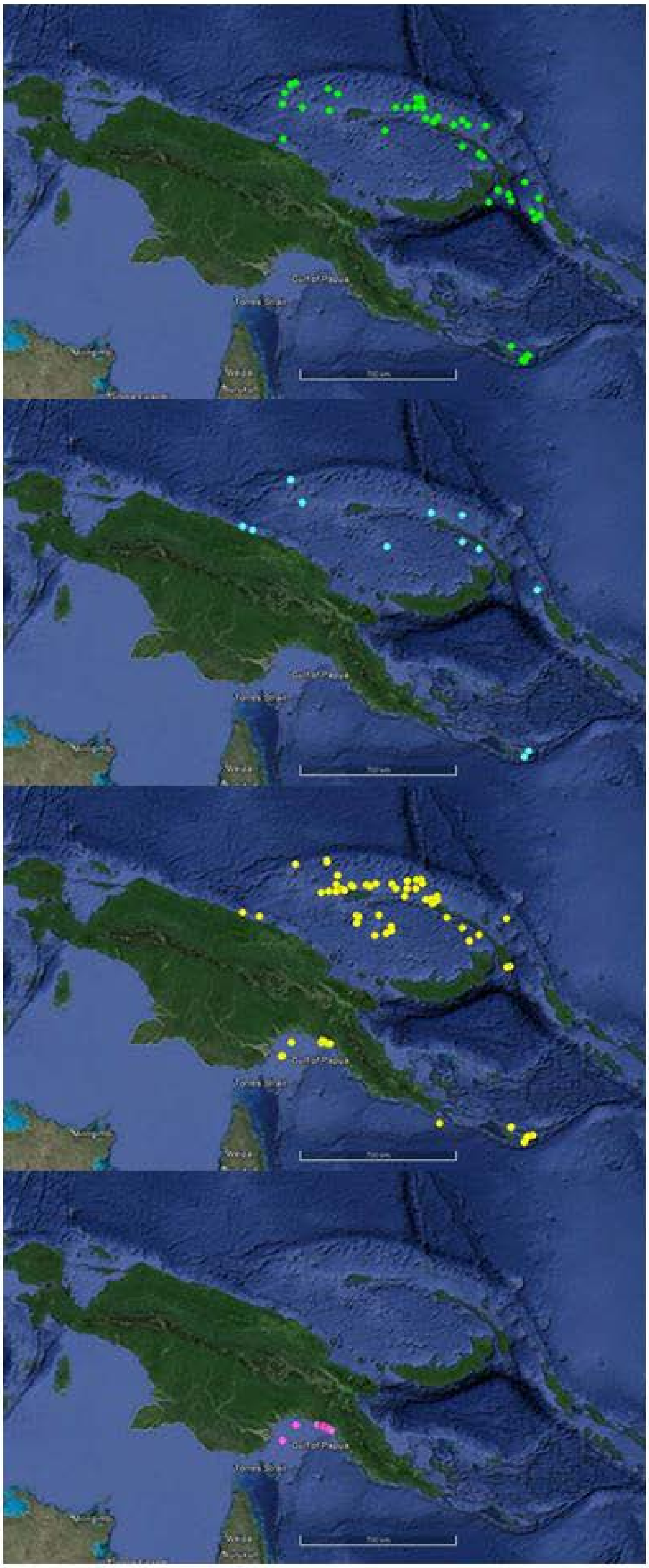

Figure 18. Distribution of scalloped hammerhed sharks (*S. lewini*) in Papua New Guinea where green indicates adult females, blue indicates adult males, yellow and pink indicate immature and neonate individuals of both sexes. Map data ©2015 Google

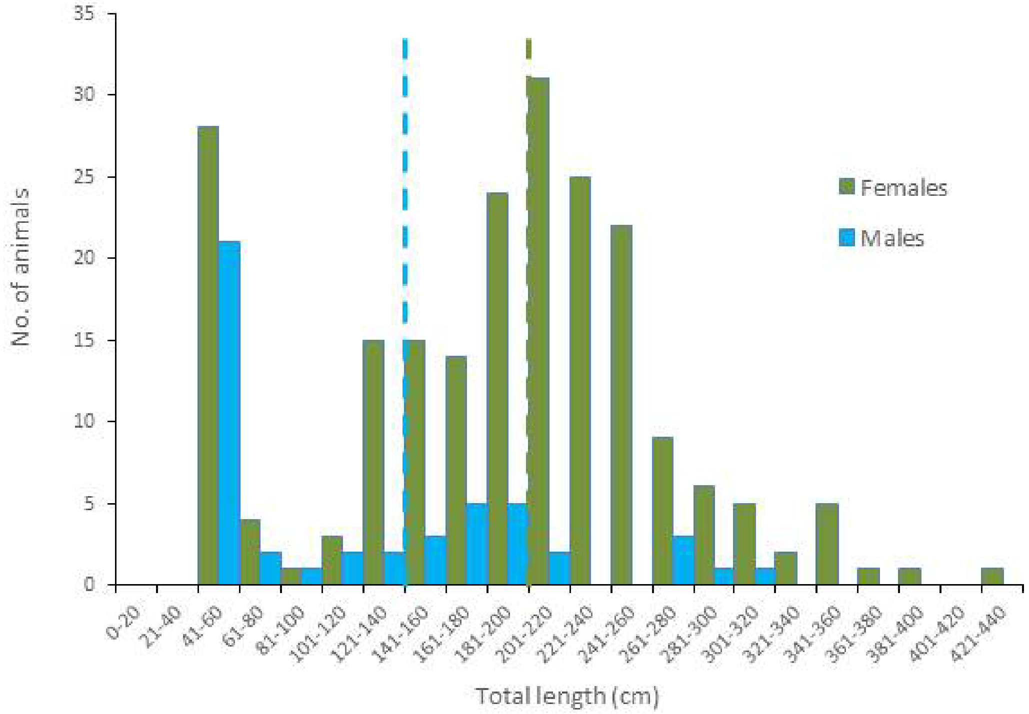

Figure 19. Size frequency of individuals encountered in Papua New Guinea by sex for *S. lewini*. Dashed lines represent corresponding size at maturity for each sex and species.

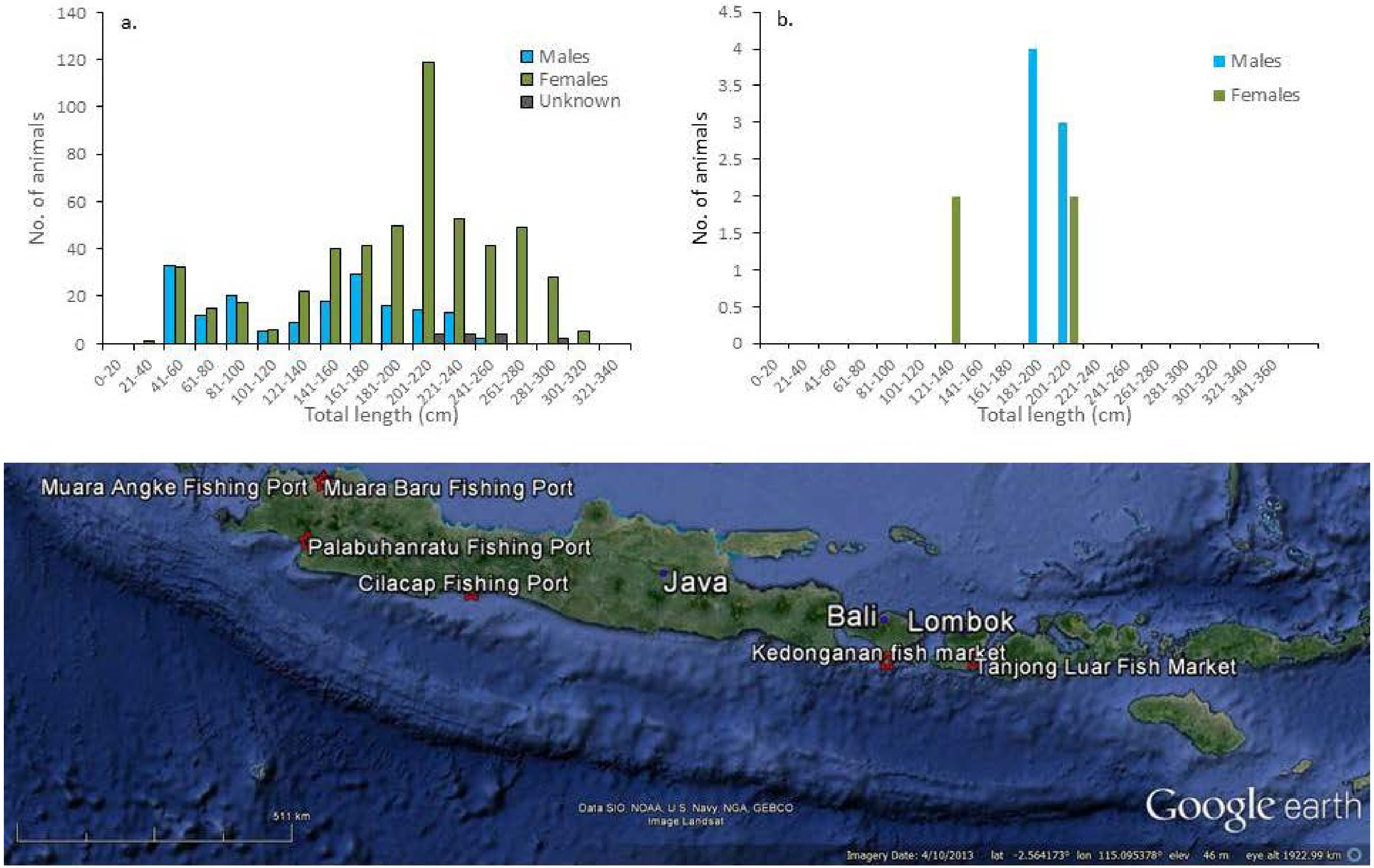

Figure 20. Market sampling in Indonesian landing ports as indicated by red symbols. Size frequency of individuals sampled for a) *S. lewini* and b) *S. mokarran*. Map data ©2015 Google

9. OTHER DATA

The final data set examined for *S. lewini* and *S. mokarran* was based on baited remote underwater video (BRUV) surveys in Qld and WA. These surveys were largely designed to examine seabed biodiversity and so weren't designed as a shark monitoring tool. However, sharks were encountered and recorded in this sampling and are independent of fishing activity. Based on this data set it was apparent that *S. mokarran* were encountered more regularly than *S. lewini*. In the GBR 41 *S. mokarran* were sighted compared to 12 *S. lewini* (Espinoza et al. 2014). Both species were also recorded in under-sampled regions including the GBR and offshore reef habitats in WA. Additional BRUV sampling in potentially important or under-sampled habitats may be useful. Application of stereo BRUVS would also allow size estimates to be determined for sighted individuals.

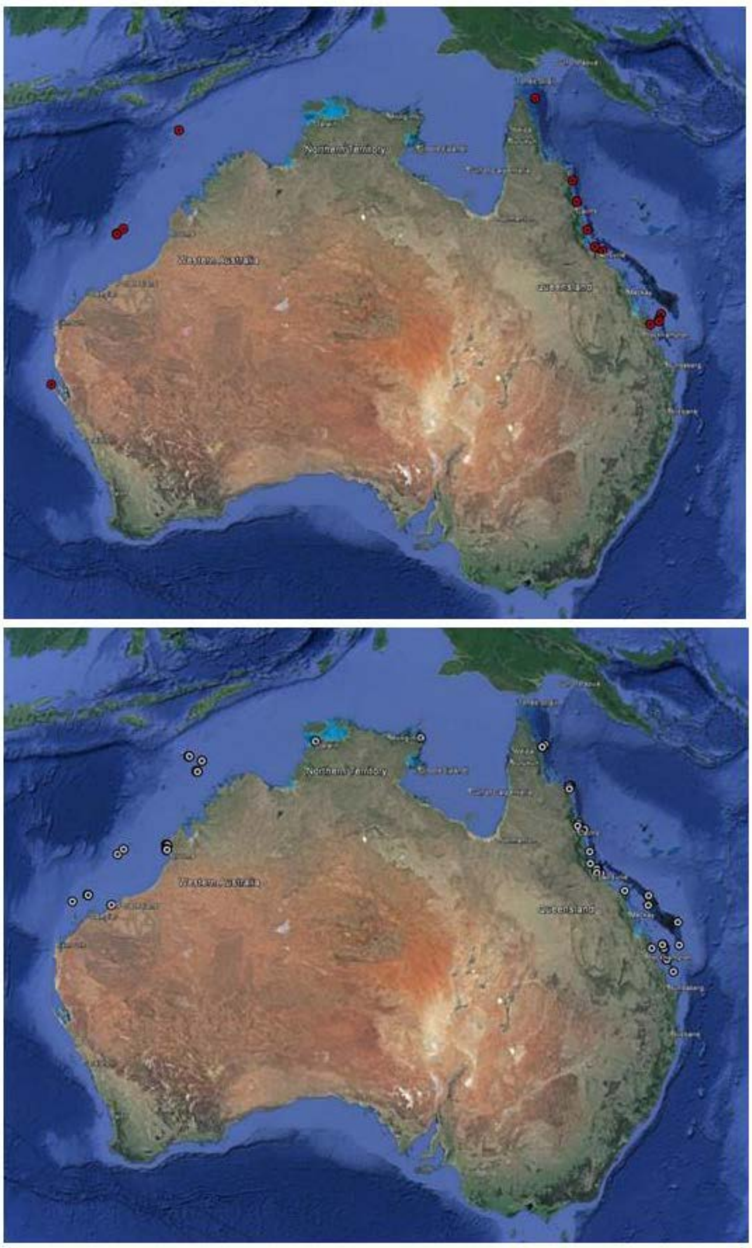

Figure 21. Incidence of hammerhead sharks on baited remote underwater video surveys for *S. lewini* (top) and *S. mokarran* (bottom). Map data ©2015 Google

Winghead sharks

Winghead sharks, *Eusphyra blochii*, are one of the least well known hammerhead species. The distribution of *E. blochii* appears to be clumped with some regions having large numbers of individuals while others reveal few encounters. For example, along the coast of Qld the Mackay region is appears to be a hotspot for *E. blochii*, while few individuals are found elsewhere in Qld. The broad-scale data suggest *E. blochii* may be more prevalent in Northern Territory waters than in Qld, WA or PNG (Figure 22). One common aspect of the clumped distribution of *E. blochii* is river outfall. It is possible this species has a preference for estuarine regions which may explain its distribution. Regional data from WA, NT and Qld reveal encounter occurs in shallow nearshore waters (Figures 23-25). Qld and WA report limited numbers of individuals, while NT shows higher encounter rates in areas that overlap with areas frequented by both *S. lewini* and *S. mokarran*. The limited data available for this species suggests increased research effort may be required to determine whether this species is naturally rare or is going undetected in fishery catch. Individuals recorded from PNG were also found close to shore with no adult males observed in this region (Figure 26). Size frequency data vary throughout the sample sites with most regions recording small numbers of immature individuals (Figure 27). In contrast, samples from NT contained much higher numbers of individuals including immature and mature individuals of both sexes. This suggests portions of the NT may be a good starting point for sampling and studying *E. blochii* populations.

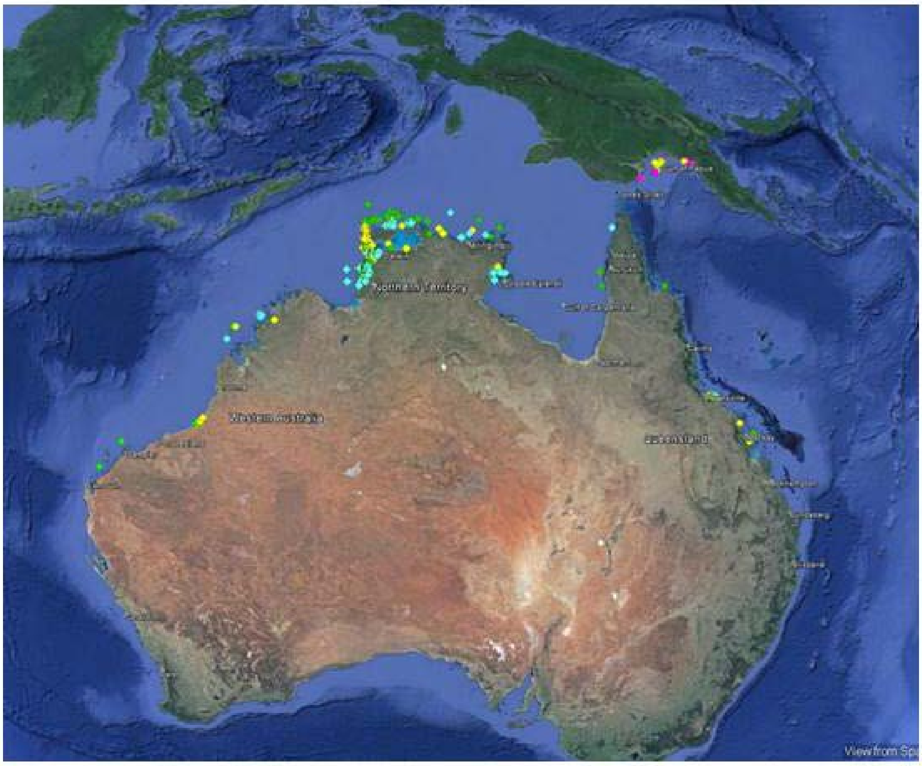

Figure 22. Location data used to define the distribution of winghead sharks (*E. blochii*). Map data ©2015 Google

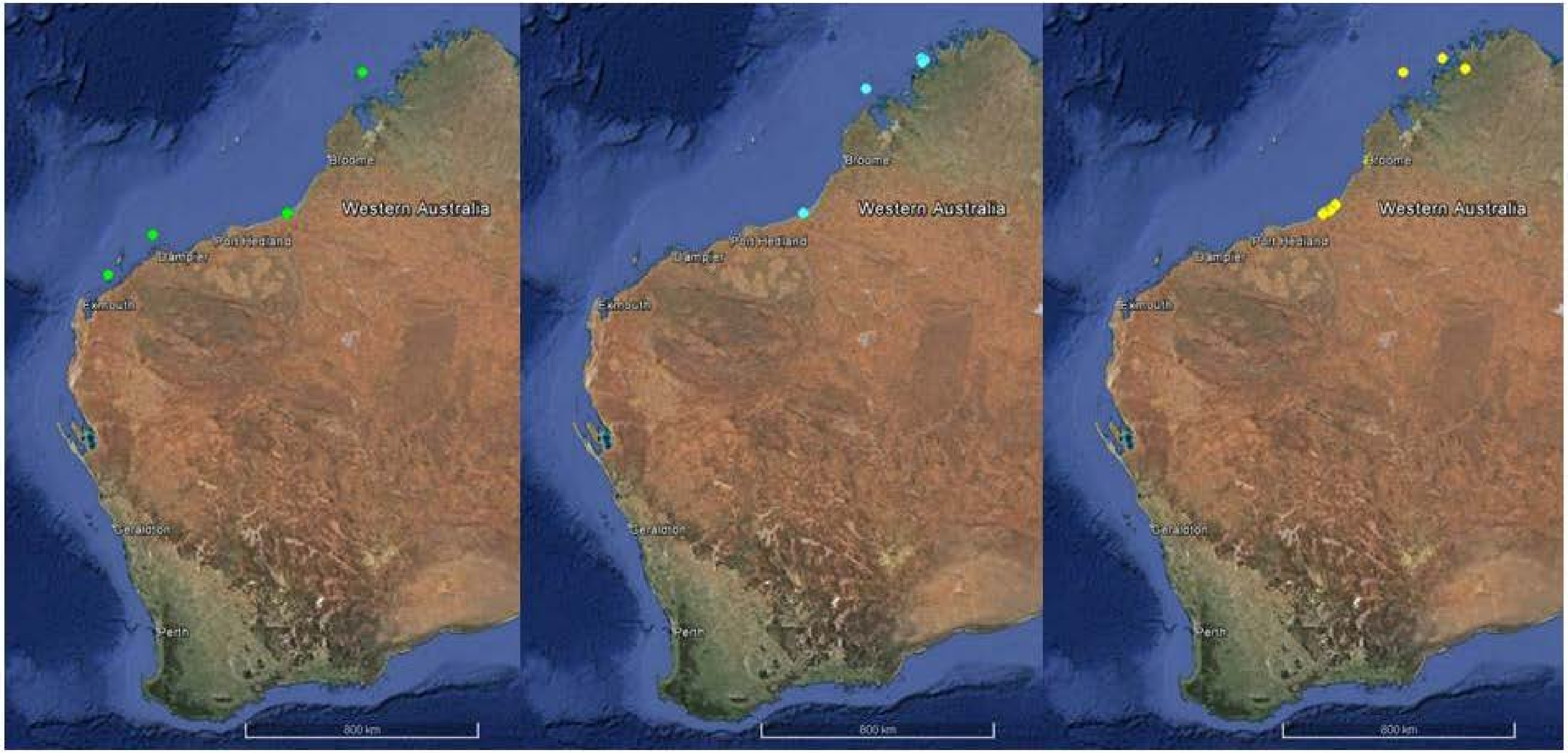

Figure 23. Distribution of winghead sharks (*E. blochii*) in Western Australia where green indicates adult females, blue indicates adult males, yellow indicates immature individuals of both sexes. Map data ©2015 Google

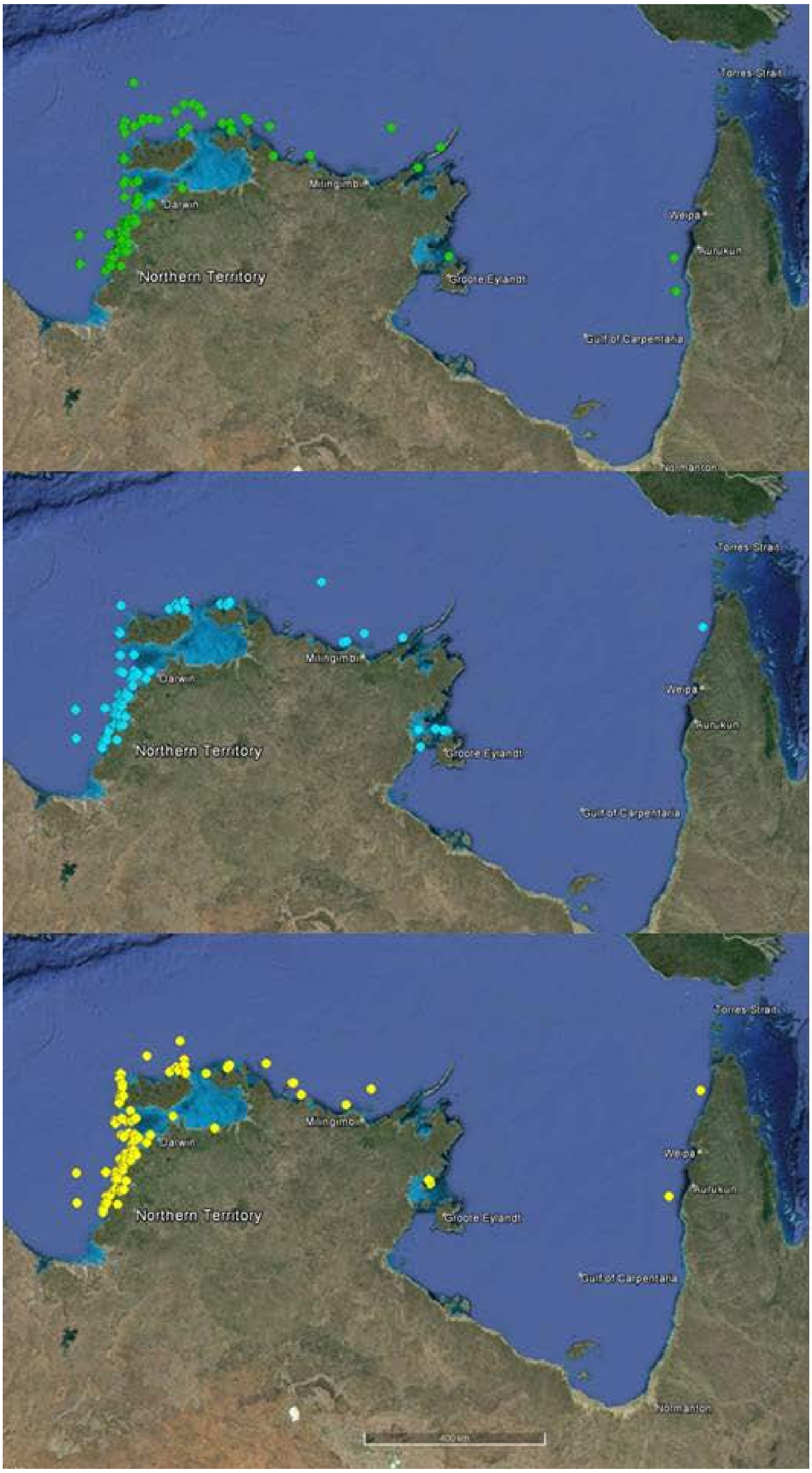

Figure 24. Distribution of winghead sharks (*E. blochii*) in Northern Territory where green indicates adult females, blue indicates adult males, yellow indicates immature individuals of both sexes. Map data ©2015 Google

Figure 25. Distribution of winghead sharks (*E. blochii*) in Queensland where green indicates adult females, blue indicates adult males, yellow indicates immature individuals of both sexes. Map data ©2015 Google

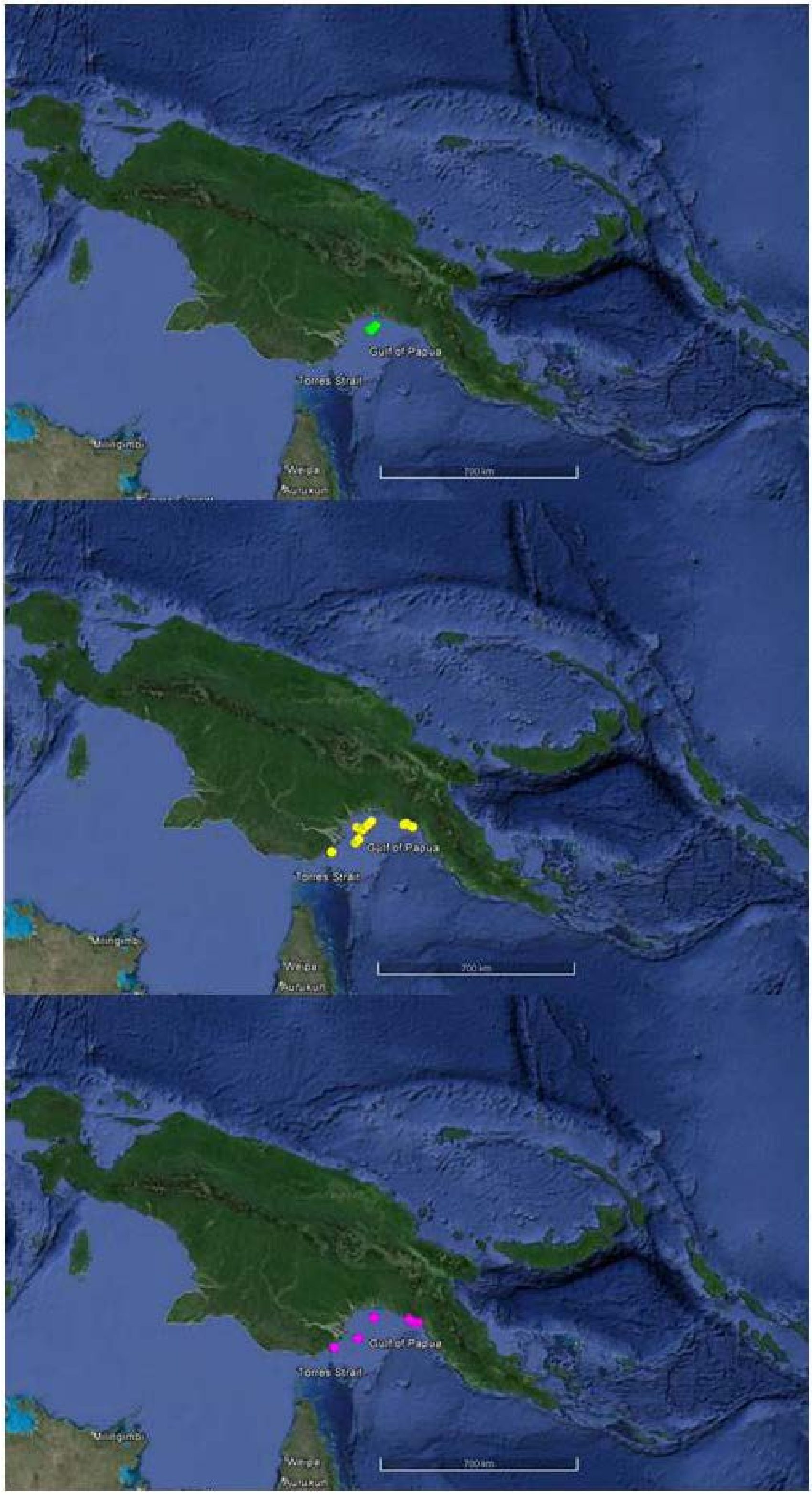

Figure 26. Distribution of winghead sharks (*E. blochii*) in Papua New Guinea where green indicates adult females, yellow and pink indicate immature and neonate individuals of both sexes. Note: no adult males have been observed. Map data ©2015 Google

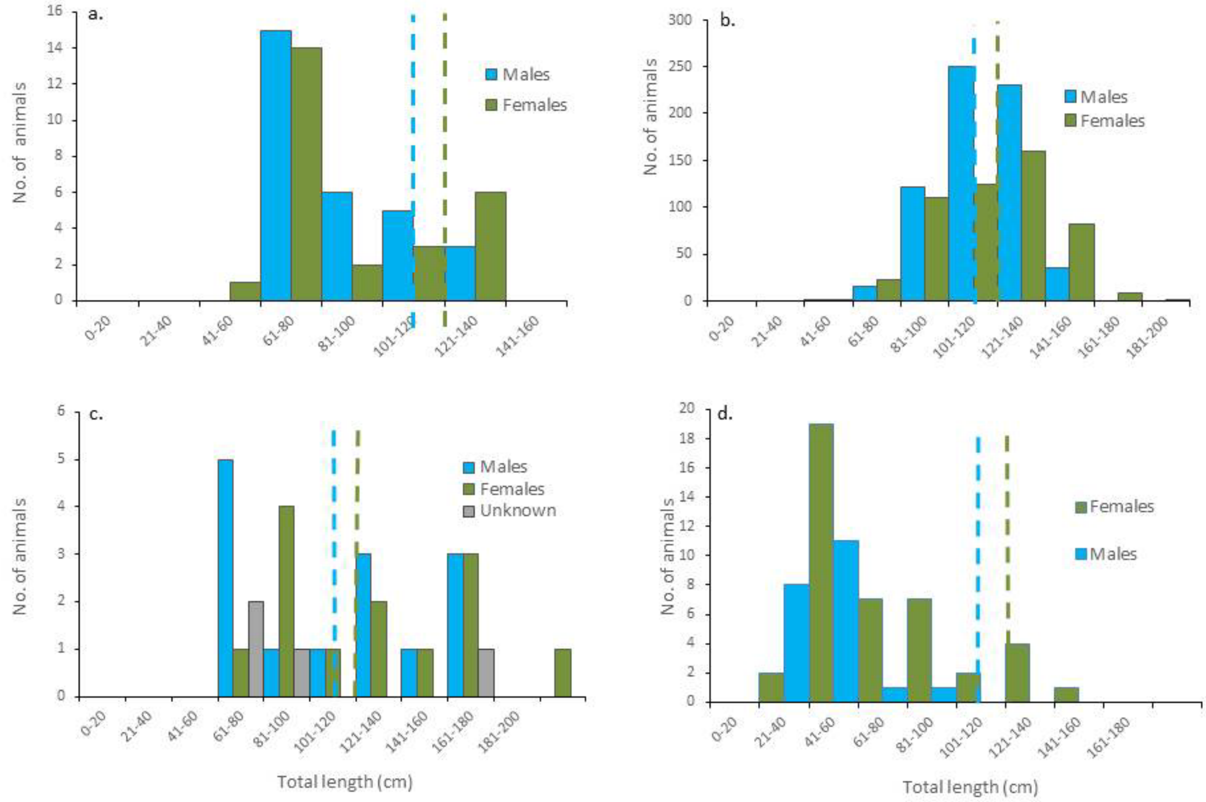

Figure 27. Size frequency of *E. blochii* individuals by sex for: a) Western Australia, b) Northern Territory, c) Queensland and d) Papua New Guinea. Dashed lines represent corresponding size at maturity for each sex and species. Note differences in axes.

10. STOCK STRUCTURE HYPOTHESES FOR SCALLOPED HAMMERHEADS

Currently there is a range of fragmentary information available to inform our understanding of the stock structure of scalloped hammerhead sharks that occur in Australian waters. This information is summarised below.

1. The size and sex structure data indicate that few adult females (and especially pregnant females) have been caught in northern Australia, while in Indonesia and PNG adult females are commonly caught (see distribution section). This has led to the suggestion that adult females migrate from Australian waters north into Indonesia and PNG, but must return to give birth to their young in nursery areas that occur in coastal areas of northern Australia (e.g. Yates et al. 2015a,b). However, it may also be a case that Australian fisheries do not operate in areas where the adult females reside. Some pregnant females have been recorded, including in the Queensland Shark Control Program data (Noriega et al. 2011) although there remain some concerns about identification of these animals (i.e. some may have been great hammerheads). Continued monitoring of data is needed for evidence of pregnant females from (1) fishers operating along the edge of the continental shelf or at offshore seamounts, and (2) divers at offshore seamounts or reefs who may encounter large schools of scalloped hammerheads as are reported from other parts of their distribution (Klimley and Nelson 1981).
2. There is genetic evidence of mixing between Australian and Indonesian animals (Ovenden et al 2009). This genetic analysis only provides evidence of a connection at very long evolutionary time scales (although it does not discount connections at much shorter time scales). This evidence does not discount the possibility that adult female scalloped hammerheads regularly migrate north from Australian into Indonesia and PNG.
3. There are a number of biogeographic barriers that have been identified in the region that may be important for structuring the population:
    a. Torres Strait Land Bridge. This may form a barrier between stocks on the east coast of Queensland and the rest of northern Australia. This has occurred for other species of coastal sharks (e.g. Common Blacktip Shark *Carcharhinus limbatus*) and coastal pelagic teleosts (e.g. Grey Mackerel *Scomberomorus semifasciatus*) (Flood et al. 2014).
    b. Deepwater between Australia and Indonesia (Java Trench). This may form a barrier to regular movement of animals between Western Australia and the Northern Territory north into Indonesia. However, the existence of genetic similarities between Australian and Indonesian specimens means this may not be the case.
    c. Wallace Line. This well-known biogeographic barrier running through Indonesia (between Bali and Lombok in the south, and running north between Kalimantan and Sulawesi) is a result of deep water that may form a barrier to movement between eastern and western Indonesia. This may mean that scalloped hammerheads west of the Wallace Line have less connection with

northern Australia compared to those from east because that region shares a continental shelf with northern Australia.

4. Genetic evidence from other parts of the world suggest that females have a tendency to remain associated with particular stretches of continental shelf and have a tendency for natal philopatry (i.e. females return to the nursery area in which they were born to give birth) (Duncan et al. 2006; Nance et al. 2011). If this would hold for the northern Australian population it would preclude a strong connection to western Indonesia. However, the shared continental shelf with New Guinea and eastern margin of the Banda Sea (Indonesia) would not preclude this connection.
5. Genetic evidence from other parts of the range indicates that males move over larger distances and have less population structure than females (Daly-Engel et al. 2012). This suggests that genetic markers that provide information on female gene flow (e.g. mitochondrial DNA) may provide different results than markers for combined sexes (microsatellites, SNPs).
6. Evidence from tagging and telemetry studies show that adult *S. lewini* will travel long distances, including across open oceans (e.g. Kohler et al. 1998; Ketchum et al. 2014). If these types of movement patterns exist within animals that occur in Australian waters then this would allow for movement between northern Australia, Indonesia, PNG and also the broader Pacific and Indian Oceans.

Based on these pieces of information it is possible to conceptualise the stock structure as a series of geographic areas linked by movement between each of these locations (Figure 28). This conceptual model can be used to develop hypotheses about stock structure and identify the evidence that would be needed to conclude which of these is most likely. These different hypotheses are provided in Table 1, and the types of genetic and telemetry results that may support or refute each of these is outlined.

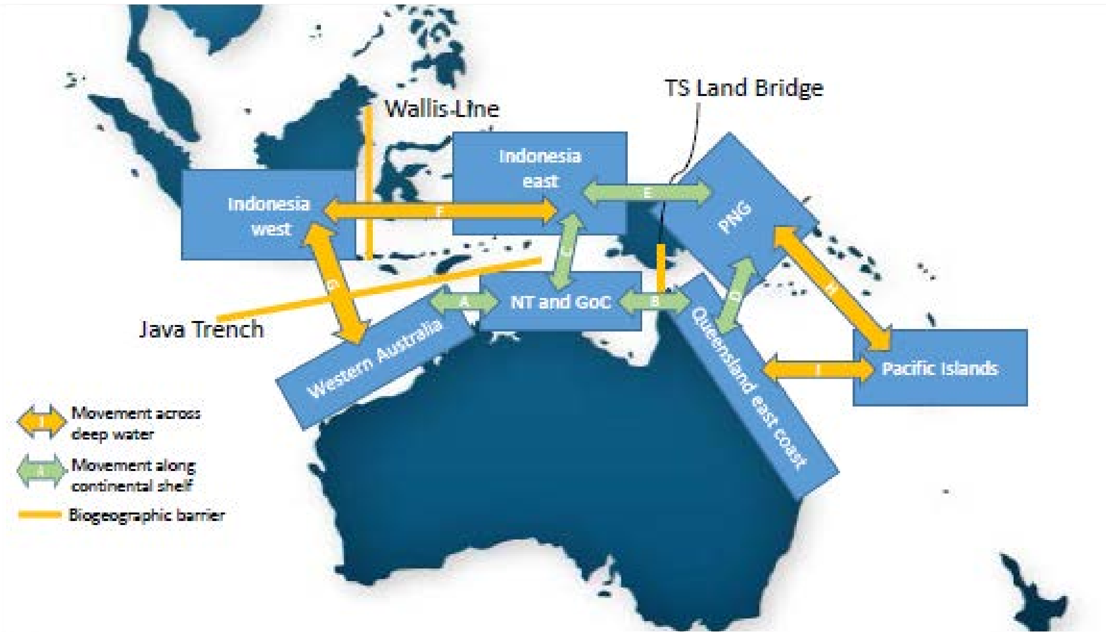

Figure 28. Conceptual population structure model of scalloped hammerhead sharks in northern Australian

Table 1. Alternate stock structure hypotheses for scalloped hammerhead sharks occurring in northern Australia.

Hypothesis	**Description**	**Current support**	**Future research results that would support hypothesis**
Panmictic population throughout region	Adults move freely through the region; adult females likely to return to natal nursery areas in northern Australia to give birth	Genetic connection to Indonesia; size and sex structure data; ability to travel across deep water (from other regions)	Genetic analysis Tests comparing Australian, Indonesian, PNG and Pacific island samples show no differences with any type of marker (mtDNA, microsatellites, SNPs). Telemetry and tagging Tracking results of adults show movements from Australian waters into Indonesian and PNG waters
Limited movement	Adults remain in restricted geographic areas (e.g. adults from Qld coast move offshore to edge of shelf or Coral Sea Reefs) but rarely move to other areas.	Limited current support	Genetic analysis Tests comparing Australian, Indonesian, PNG and Pacific island samples show significant differences between regions (possibly including within Australia) with any type of marker (mtDNA, microsatellites, SNPs). Telemetry and tagging Tracking results shows movement of adults to offshore areas but no long distance movements to Indonesia and PNG. Fishing or diver surveys Sampling shelf edge habitats and offshore seamounts identifies significant populations of adults (especially pregnant females).
Continental shelf movement	Adults move along the margins of continental shelves, including	Genetic connection to Indonesia; size and sex structure data;	Genetic analysis Tests show connectivity between Australian

Hypothesis	Description	Current support	Future research results that would support hypothesis
	northwards into eastern Indonesia (eastern Banda Sea) and PNG	evidence of residency to continental shelves in other regions; ability to move large distances	samples and eastern Indonesia (eastern Banda Sea and West Papua) and PNG, but not western Indonesia and Pacific Islands. Telemetry and tagging Tracking results shows movements along continental shelves, but not across deep water.
East-West Australian stock divide and continental shelf movements	Similar to the previous hypothesis but Torres Strait land bridge divides stocks to the east and west, with adults moving northwards into Indonesia (from WA, NT) or PNG (from Qld)	Similar to previous hypothesis; Torres Straight Land Bridge has caused population structuring in other sharks and teleost species	Genetic analysis Tests show (1) connectivity between eastern Indonesia (eastern Banda Sea and West Papua) from NT and WA only, and PNG from eastern Queensland only; (2) no genetic connectivity with western Indonesia and Pacific Islands; 3) no genetic connectivity between eastern Queensland and the rest of northern Australia. Telemetry and tagging Tracking results shows movements along continental shelves but not through Torres Strait Land Bridge or across deep water

These four potential hypotheses may also vary between sexes given the evidence that males have a broader range of movements than do females (Daly-Engel et al. 2012). Thus one hypothesis may hold for females, but another for males. The use of a range of tools (e.g. mitochondrial DNA, microsatellites, SNPs, telemetry of males and females) that can address these sex differences would need to be employed to resolve these uncertainties. Resolution of the stock structure of scalloped hammerheads will provide greater certainty in relation to conservation planning for this species in Australia (and potential neighbouring nations). Similar considerations for the stock structure of great hammerheads may also be required, but there is little existing data on which to start building hypotheses. However, a similar approach would likely be necessary to that applied to scalloped hammerheads.

11. CONCLUSIONS

Synthesis of the available data on hammerhead shark size and sex distribution revealed the complexity of hammerhead shark presence and movement patterns. The data indicate differences in the composition of *S. lewini* and *S. mokarran* populations. Sampled *S. lewini* were predominantly immature and adult male individuals, while *S. mokarran* were encountered across a broader size range and included nearly equal numbers of males and females. This suggests sexual segregation may be more prominent in *S. lewini* than *S. mokarran* in Australian waters. It should be noted though that *S. mokarran* was encountered less frequently. It is unclear if this is due to this species being less common in the region, a result of depletion, or an indication that suitable habitats have not been well sampled. Further sampling and monitoring is required to fully understand the differences in size and sex ratios apparent between the two species.

Regional and broad-scale analysis indicated several gaps in current data. Several regions are less well sampled than others. For example, less populated, remote regions such as the Gulf of Carpentaria and NW Western Australia had lower numbers of samples than adjacent regions. This is likely the result of limited sampling than the lack of species occurrence. In addition, some regions have had little or no sampling effort including potential crucial areas of population connectivity such as Torres Strait. Analysis of data from PNG also indicates sea mount or oceanic ridge habitats may be important for scalloped hammerheads. These habitats are typically not fished in Australian waters and are therefore under-sampled. Future research should consider sampling these potentially important habitats. It is possible that these regions are preferred habitat of adult females or are the location of aggregations of hammerhead populations. Nearshore habitats are important for neonate and juvenile individuals but further sampling should be undertaken to better define use of these regions. Definition of the characteristics of regions with high encounter rates would allow sampling to be focused in regions with similar conditions. It is possible that habitats are used disproportionately even along continuous stretches of coastline (e.g., Yates et al. 2015a,b). Thus habitat preferences should be explored to help define any biologically important areas for these species. This information will help guide research and could be used to establish environmental or spatial management conditions if required.

Based on the current data it is unclear how much individuals move between regions and what is causing differences in size and sex class distributions. This lack of data precludes any estimation of connectivity within and beyond Australia. Although stock structure models can be developed, current data are not adequate to discard any of the current hypotheses. Understanding current and historic connectivity within and beyond Australia is crucial to defining appropriate management for hammerhead populations in Australia. Current management is handled primarily by State and Territory agencies, if high connectivity is present a joint-jurisdiction approach needs to be adopted. If connectivity extends to Indonesia and PNG broader cross-jurisdictional management arrangements need to be considered. Thus connectivity needs to be resolved as a matter of priority. An approach that examines movement as well as genetic connectivity should be applied. Previous genetic analyses suggest connectivity, but detailed studies using additional samples and new approaches should be applied to explore the level of potential connectivity in greater detail.

Given the propensity of hammerheads to interact with inshore gillnet and line fisheries continued monitoring and improved data collection are required. Species-specific catch data including size and sex information is extremely valuable to defining distribution patterns. For example, if fisheries are encountering adult females these data will be critical to improving our understanding of this portion of the population. Due to the potential difficulties associated with species identification, additional measures are likely required. Implementation of observer programs or photographic records of catch may be required to help define catch composition at a level that will be useful for management and conservation decision-making. Post-release survival rates of hammerheads are also not well known and should be explored. If individuals that interact with fisheries have high rates of mortality this may alter the management approach applied to these species.

Encounters with *E. blochii* should also be explored to help define what role this species plays in the region and if there are any implications of *E. blochii* catch. The complexity of identifying hammerhead products post-processing means that *S. lewini* or *S. mokarran* products could be landed, but labelled as *E. blochii*. After processing, discrimination of fins will require genetic analysis as the differences among species are slight. Recording *E. blochii* catch should be undertaken as part of improved species level reporting described above. Consideration should be given to whether hammerhead sharks must be landed with the head attached. This would allow positive identification to be made at the point of landing. Improved understanding of catch and landings will also help inform obligations to monitor trade of hammerhead products as required under current CITES listings.

Full definition of the status of Australia's tropical hammerheads requires a significant amount of additional data. This analysis highlights what is currently known, where knowledge gaps are present and provides several hypotheses related to the stock structure of scalloped hammerheads. Continued monitoring and additional research are a priority for developing effective conservation and management policy around these species. This should include:

- Species-specific data in fisheries catch, including size and sex where possible
- Examination of population connectivity via movement and genetic approaches
- Examination of post-release survival after fishery interaction
- Improved data sharing between State and Territory agencies
- Consideration of product identification to avoid exploitation via recording product as that of a similar species (e.g., *E. blochii*)

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