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Sustainable management of the shark resources of Papua New Guinea: socioeconomic and biological characteristics of the fishery

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2 Executive summary

Sharks and rays are Papua New Guinea's (PNG) 5th most important export fishery, but there was very little data available on sharks and rays in PNG waters. This project aimed to provide detailed information on key shark and ray species in PNG and a framework to enable PNG to manage its shark and ray resources sustainably. To achieve this, the project set out to describe the biological, social, economic, catch and gear characteristics of the fisheries exploiting sharks and rays and assess the status of the stocks of key shark species and the extent to which they are shared with adjacent countries. In addition, detailed biodiversity data were collected and important specimens were deposited in the national fish collection housed at the University of Papua New Guinea (UPNG).

Detailed catch composition data were obtained from the prawn trawl and shark and tuna longline fisheries through the NFA's observer program. Detailed catch data were also obtained from coastal fisheries in a number of provinces. Age and growth and reproductive data were documented for a number of key shark species. This regionally-relevant data was critical for accurate demographic analyses which were conducted for three of the key shark species. Population structure and connectivity was also investigated for three key shark species.

Biodiversity information was collected throughout the project from a wide array of sources, including museums (local and international), observer data, coastal surveys, opportunistic sampling, and literature records. A total of 132 species of sharks, rays and chimaeras were verified from PNG, with around 10 new species described and more than 40 species not previously confirmed from PNG. This information, together with biological and fisheries data, was used to produce a field guide to the sharks and rays of PNG which had a primary goal of improving identification of sharks and rays in the future.

The catch composition data obtained from the various fisheries found a large proportion of shark fins retained and dried for export belong to CITES listed species. Since PNG is a party to CITES, this represents a significant challenge in the immediate future for NFA to ensure compliance with international regulations. Future research and capacity building needs to be undertaken to ensure the processes for meeting these obligations are understood and acted on.

The project supported a number of students, 3 PhD's (1 PNG, 2 Aust.), 2 Honours (1 PNG, 1 Aust.) and 2 Masters (Aust.). This represents a significant capability boost for both NFA and PNG. The socioeconomic component highlighted a high dependence on shark and ray products by some local coastal communities as well as finding that the shark fin market chains are highly dependent on the sea cucumber market chains. This is crucial information for future management of sharks in PNG as it highlights the fact that changes to sea cucumber management will directly affect shark management in coastal fisheries.

The information and data collected in this project will have a long-lasting impact in PNG as it forms an important baseline for all future research. In particular, the demographic analyses highlight that, left unchecked, population declines of key shark species are highly likely. The capacity building tools, e.g. field guide, protocol guides, shark and ray museum specimens, will also be important for future research on sharks and rays in PNG.

Future research on capture fisheries in PNG should focus on the coastal fisheries sector for which there is a real paucity of data. Although a relatively data-poor sector, more livelihoods are involved and in many cases these livelihoods are dependent on fisheries resources. Thus, more focus needs to be placed into this sector.

3 Background

Sharks and rays (chondrichthyans) are considered to be particularly vulnerable to over-exploitation as a result of their large body size, low fecundity, slow growth, late age at maturity and long life spans, i.e. they have K-selected life-history strategies (Stevens et al., 2000). Population declines and localised extinctions have been documented for a number of shark species. The conservation of both the biodiversity and the populations of chondrichthyans are critically important to maintain healthy marine ecosystems (White & Kyne, 2010).

There is growing regional and international concern about the sustainability of shark populations and, in many countries, there are increasing moves to limit shark fishing. In line with the FAO's International Plan of Action for Sharks (IPOA, http://www.fao.org/docrep/003/y1224e/y1224e00.htm), PNG has an obligation to actively manage its shark fishery to ensure that the resource is fished sustainably both from an environmental and an economic perspective. Proper management of the shark fishery would minimise negative perceptions that may tarnish the reputation of other Papua New Guinean fish products or result in the longline fishery being halted. This research will also provide information that could inform fishers and allow them to better contribute to management objectives.

There is no detailed information on the sustainability of the fisheries which interact with sharks and rays in PNG. It is also highly likely that the shark resources of PNG are shared with neighbouring countries, e.g. Australia, Indonesia, and adjacent South Pacific island nations such as the Solomon Islands. Population declines of key shark species can affect livelihoods of communities reliant on those resources, e.g. coastal fishers or ecotourism operators, thereby having important economic ramifications. In 2011, The PNG National Fisheries Authority (NFA) identified a need to develop better fisheries management practices, underpinned by an assessment of the shark and ray fisheries, to ensure economic sustainability, intergenerational equity and conserve cultural significance, and to meet international conservation obligations.

Prior to the current ACIAR study, the shark and ray fauna of PNG was not well understood, especially in regards to the deepwater species present in PNG waters (Last & White, 2011). It is critical to have a good understanding of the species occurring in the region to act as a foundation for developing adequate fisheries management plans for fishery operations which may expand or develop in the future.

The main fishery for sharks in PNG was the target shark longline fishery, which operated out of Rabaul, and was regulated by the Shark Management Plan developed by the NFA and implemented in mid-February 2001 (Kumoru, 2003a, b). This fishery ceased operation in July 2014. In addition, sharks are also caught as bycatch by the tuna longline fishery, operating out of Port Moresby, and the tuna purse-seine fishery (~200 vessels from 13 nations in 2007, Nicol *et al.*, 2009). Previous analysis indicated that shark products were ranked as PNG's 5th most valuable fishery export commodity in 2002, after tuna, prawns, *beche-de-mer* and lobster; shark products are worth about K8 million annually (Kumoru, 2003b).

Prior to this project commencing, there was no information on the level or composition of the shark and ray catches in the coastal fisheries throughout PNG and very limited information on the shark and ray bycatch in the Gulf of Papua prawn trawl fishery. Bycatch species composition in the trawl fishery was largely unknown and may include exploitation of local endemic species. This project aimed to provide important information on the exploitation of sharks and rays from these fisheries and, in doing so, address important IUU (Illegal, Unreported, Unregulated) issues in PNG, in particular the unreported and unregulated components. Improved capability for species identification underpins accurate reporting of the exploited shark and ray species from the various fisheries. For some fisheries, such as the prawn trawl fishery in the Gulf of Papua, systems to prevent fishing in prohibited areas (e.g. inshore coastal waters) are already in place.

As there had been no research undertaken on the status of sharks stocks in PNG waters, there was an urgent need to assess whether the current management plan was sufficient to ensure sustainable use of these resources into the future. Recent research on Indonesian shark fisheries (the largest in the world) has highlighted the need for better management of shark resources and the importance of understanding the level at which stocks of key species are shared with northern Australia (Blaber *et al.*, 2009). There is an ongoing important need to understand the extent to which PNG shark stocks are shared with Australia and Indonesia and to determine whether co-operative management between countries with shared stocks needs to be improved (currently shark fisheries also falls under the auspices of the Western and Central Pacific fisheries Commission for regional management, of which Australia, PNG are members and Indonesia is a cooperating non-member).

Population genetic studies contribute the necessary knowledge on the extent to which key target species are shared with adjacent geographic regions. However, within this single project, detailed population genetic analyses could only be carried out for several key target species. The species considered the highest priority for population genetic analyses were the Scalloped Hammerhead *Sphyrna lewini*, Silvertip Shark *Carcharhinus albimarginatus* and Grey Reef Shark *Carcharhinus amblyrhynchos*. The Scalloped Hammerhead was given highest priority as it is was recently listed as Endangered in the IUCNs Red List of Threatened Species and added to CITES Appendix 2 due to its high level of exploitation and low productivity. Hammerhead sharks are an important component of the PNG shark longline fishery (Kumoru, 2003b), and the Scalloped Hammerhead *S. lewini* is typically the most abundant hammerhead species. Previous genetic studies of this species both within and across oceanic basins have produced different outcomes on global and regional scales (Duncan *et al*., 2006; Ovenden *et al*., 2009; Nance *et al*., 2011; Ovenden *et al*., 2011). While there is no information on the population structure of *S. lewini* within regional PNG waters, there is some information on the species in neighbouring Indonesian and Australian areas (Ovenden *et al*., 2009; Ovenden *et al*., 2011). The Silvertip and Grey Reef Sharks have not had detailed population genetic studies conducted previously and their strong association with reefs made them priority species to determine their population structures. A combination of mitochondrial DNA (mtDNA, maternally inherited) and nuclear markers (microsatellites and single nucleotide polymorphisms (SNPs) (bi-parentally inherited markers)) provided platforms for testing philopatric maternal movements versus bi-parental gene flow and connectivity.

Overall, improved fishery and conservation management of sharks and rays (as developed in the current study) will lead to greater sustainability of these resources which will likely benefit coastal fishers as well as ecotourism-based operators, particularly diving. Furthermore, there is increasing evidence from around the world that overfishing of apex predators, such as sharks and rays, can have deleterious top-down effects on the whole marine ecosystem. If current management practices are not adequate then populations of sharks and rays in PNG may rapidly decline, which could have a flow on effect to other fishery resources. This could have significant ramifications on the livelihoods of communities which rely on shark and ray resources as a source of income. Shark and ray ecotourism has been shown to be particularly lucrative in many regions of the world and such activities could likely be expanded in PNG. But this requires healthy populations of sharks and rays which are exploited sustainably to ensure longevity of any ecotourism ventures. Thus, it is important to gain further insights into the diversity of sharks and rays in PNG thereby contributing to management decisions in the future. In addition, this research contributes to the international reputation of PNGs fisheries management approaches by enabling PNG to meet obligations under international agreements on sustainable management of shark and ray resources.

The current research will also benefit Australian fisheries managers as it will (mostly through the stock assessment component) improve our understanding of the biology and stock status of key species across regions. This in turn will help Australian fisheries managers to understand where responsibilities lie, especially in the case of shared stocks. Similarly, the project benefits other neighbouring countries, particularly other South Pacific island nations.

Underpinning this research was the development of a capability base that will allow similar research to be conducted in the future. Training was carried out in a variety of disciplines including, taxonomy, genetic techniques, biology and stock assessments. This project addressed the following research questions which are crucial for PNG to develop better management options for their shark and ray resources:

1. Is current management of shark fisheries in Papua New Guinea suitable for the sustainability of these resources and delivering desirable socioeconomic outcomes?
2. Are populations of the main exploited shark species in Papua New Guinea shared with Australia and/or Indonesia?

4 Objectives

The aim of this project was to provide sufficient information and a framework to enable PNG to manage its shark and ray resources on a sustainable basis.

Specific objectives were:

1. Describe the biological, social, economic, catch and gear characteristics of the fisheries exploiting shark and ray resources;
2. Assess the status of the stocks of key species and determine the extent to which they are or could be shared with Australia and Indonesia and advise on necessary changes to current management plans;
3. Develop a well-maintained fish collection and technical tools to facilitate management and conservation of shark and ray resources.

5 Methodology

5.1 Observer program (longline and trawl fisheries)

5.1.1 Training and data sheets

A large portion of the project was reliant on an intensive observer program that was conducted on the shark and tuna longline and prawn trawl vessels over approximately 2 years. Two training protocol guides were produced for observers which covered aspects such as: gear needed, basic shark anatomy, photography, data and sample collection (e.g. vertebrae for age and growth studies) and species identification:

- *Manual for data collection and species identification of sharks from longline vessels in Papua New Guinea* (Appendix 1)
- *Manual for data collection and species identification of sharks and rays from prawn trawl bycatch in Papua New Guinea* (Appendix 2)

A workshop (to provide additional training on data collection for this project) was held in March 2014 in both Port Moresby and Rabaul to train the NFA longline and trawl observers and de-briefers to be used during this observer program.

Since the NFA observers were experienced and familiar with the SPC data sheets for longline fisheries, existing species and biological datasheets were modified rather than developing whole new datasheets. Thus, the relevant biological data collection form for longline observers, LL4 form, was modified to capture shark specific maturity information and whether samples were retained, as well as linking to a unique label number to ensure traceability of data when samples were retained. A modified LL4 form was produced for both the longline (Appendix 3) and trawl (Appendix 4) observing. The datasheets also allow for recording of the condition of the catch, i.e. dead, alive, dying or moribund, to be used to assess survivability of captured sharks or rays.

5.1.2 Longline observers

Key species from the longline fishery, for which genetic and vertebral samples were targeted, were determined based on previous NFA reports from the shark longline fishery. These include: the silky shark *Carcharhinus falciformis*, oceanic whitetip *Carcharhinus longimanus*, scalloped hammerhead *Sphyrna lewini*, silvertip shark *Carcharhinus albimarginatus* and grey reef shark *Carcharhinus amblyrhynchos.* Longline observers were asked to focus on obtaining vertebral sections and reproductive and maturity data from these key species, but also asked to collect from other species where possible. Frozen vertebral samples collected during the longline observer trips were stored in freezers until they could be transported to the ageing facilities at James Cook University in Townsville. Genetic samples for the population genetic component were taken from frozen vertebrae once received in Australia to minimise the work needed to be undertaken by observers during the fishing trip. Observers were asked, if time permitted, to obtain genetic samples from the mother and all embryos for any pregnant females observed for possible subsequent multiple paternity research. Genetic samples were sent to CSIRO marine laboratories in Hobart.

For the shark longline fishery, 7 NFA observers were deployed from Rabaul in May 2014, which covered fishing areas in the Bismarck Sea and to a lesser extent the Solomon Sea. For the tuna longline fishery, 10 NFA observers were deployed from Port Moresby between May 2015 and October 2016, with fishing occurring in the northern Coral Sea.

5.1.3 Trawl observers

Since species identification was a more significant issue for observers on the trawlers, due mostly to the high diversity of inshore ray and shark species encountered, a different process of data collection was instigated. Within a trawl set, observers were asked to retain all specimens less than ~50 cm in size whole in a single bag. Any larger specimens were photographed and a genetic sample taken. This ensured 100% verification of species identification by either subsequent examination of retained specimens or validation using images or genetic data for non-retained specimens.

Retained frozen specimens were processed at UPNG following trawl trips and vertebrae taken from any specimens not retained whole for the fish collection.

A total of 7 NFA observers were deployed from Port Moresby between June 2014 and August 2015, with fishing occurring in the prawn management zones in the Gulf of Papua.

5.1.4 Observer database

An access database was established to capture all observer data collected in this project. The database was also used to captured all coastal fisheries and opportunistic data collected during the project. The observer database was developed and housed for the duration of the project at CSIRO in Hobart.

5.2 Coastal fisheries surveys

The catches of sharks and rays from coastal fisheries was also investigated, by undertaking surveys of key areas and interviewing coastal fishers, to determine the level of exploitation of sharks in these fisheries.

Surveys were undertaken in a variety of locations to capture a diversity of fishing types, environments and known level of fishing activity. The coastal fisheries survey trips include:

1. Daru region in Western Province (including Daru, Katatai, Kadawa, and small fishing camps) in October 2014 – selected based on the high level of inshore gillnetting targeting barramundi and jewfish which would result in shark and ray catches. The muddy inshore environment also differs from many of the other more coral reef dominated locations. CSIRO, JCU and NFA staff conducted this trip, with assistance obtained from an NFA observer, provincial fisheries staff (Daru) and a local police officer.
2. Fisherman's Island and Yule Island in October 2014 – opportunistically selected based on ease of access from Port Moresby. Trip undertaken by JCU and NFA staff.
3. Kavieng in New Ireland in October 2015 – selected based on NFA fin data examined which indicated overall low catches but with a dramatic increase in shark fin production in a previous year (later shown to be erroneous). CSIRO, doMar, NFA staff conducted this trip with assistance obtained from the National Fisheries College and the crew of their vessel the *Pokajam*, and provincial fisheries staff (Kavieng).
4. Buka in Bougainville in October 2015 – selected based on its geographic location and data showing that some shark fin production occurs. CSIRO staff conducted this trip with assistance obtained from the provincial fisheries staff (Buka).

5. Alotau in Milne Bay in March 2016 – selected due to Milne Bay Province having the highest level of shark fin production in PNG and based on findings from an earlier socioeconomic field trip.
6. East Sepik in November 2017 – selected based on information obtained in a separate project which highlighted a target shark fishery at mouth of the Sepik River as well and a large trap fishery off Wewak. JCU, NFA and UPNG staff conducted this trip with assistance from provincial fisheries staff.

Whole sharks or rays, or carcasses, observed during the survey trips were identified, biological data recorded, and genetic and vertebral samples retained.

All dried fins recorded during these surveys were sampled in order to obtain information on what species were present and the size ranges of those species. The methodology for sampling dried fins is as follows:

1. Isolate all first dorsal fins from remaining fins;
2. Allocate a unique number (using pre-printed labels) to each of these fins;
3. Photograph each fin;
4. Measure the fin height, anterior margin length and total fin length;
5. Take a small genetic sample (labelled with number from point 2);

Although some species can be accurately identified based on their first dorsal fins, genetic barcoding was required to accurately identify most of the fins.

5.3 Socioeconomic surveys

A staged approach involving field trips and a case-study approach was used to deliver the socioeconomic component of the project. This work was led by doMar Research and assisted by NFA staff.

The first field trip focused on Port Moresby in February 2014. This trip focused on collection of domestic shark fin trade data, shark export data and shark catch data collected by NFA. Interviews were also held with shark fishery stakeholders including the two shark longlining companies and a prawn trawling company (United Seafoods). Key contacts were also identified to assist with the next stages of the project.

The remaining field trips focused on collecting socioeconomic data from provinces and local level government (LLG) areas where NFA data identified significant production of shark fin. These included:

1. Milne Bay Province in November 2014 – collected data from relevant stakeholders in Milne Bay Province with a focus on the Louisiade LLG area and buyers in Alotau;
2. New Ireland Province in October 2015 – combined with the coastal fishery survey trip;
3. Manus Province in October 2015 - collect data from relevant stakeholders in Manus Island.

Socioeconomic data were collected via a combination of face-to-face interviews and focus groups, guided by surveys that were developed for shark fin buyers (Appendix 5) and shark fishers (Appendix 6). Data collected included:

1. Fishery characteristics: information on catch and income-composition, the fishing gear and methods used, and the length, frequency and location of fishing trips.
2. Fishing costs and inputs: estimates of key variable fishing costs, capital costs and labour use.
3. Views and attitudes: in relation to fishery management, the current state of the resource, future expectations and likely responses to changes in prices and catch rates.
4. Household characteristics and livelihood strategies: information on fisher's households and sources of income and food.

Collected data were also supplemented with official data collected by the NFA from large scale buyers of shark fin and other marine commodities and other shark catching fisheries.

Data were analysed to estimate average vessel profitability, returns to labour and employment. Shark related food and income sources were evaluated and compared to alternative sources to assess dependence on shark resources. Cultural values were also identified where relevant. Current governance structures, social institutions, knowledge and attitudes amongst fishers and the broader community were evaluated.

The combined analysis allowed an assessment of the potential social and economic impact of any proposed changes to fishery management as well as identification of potential management approaches to improve resource sustainability and local community welfare.

5.4 Dive industry surveys

This was a small component of the original project proposal and was further reduced in scope based on the need for an increase in attention to the prawn trawl and coastal fisheries components. During coastal fisheries surveys or via email correspondence, interviews were held with dive operators in key areas, e.g. Port Moresby, Kimbe Bay, Kokopo, Kavieng, and Milne Bay. Information gathered was largely anecdotal information on how important sharks and rays were for their operations and whether they have noticed a decline in shark and ray abundance. Images of any shark and rays photographed were also requested to assist with the biodiversity components of the project. A dive information sheet (Appendix 7) and species identification guide (Appendix 8) was developed to facilitate this.

In addition, experienced divers who have a long record of diving in PNG were also contacted to provide any images to verify species records. This component was conducted by CSIRO.

5.5 Age and growth determination

The age and growth component was conducted at JCU in their shark ageing laboratories. Ageing work requires a drying oven, double bladed bone saw, microscope with a camera attached that is also connected to a computer and appropriate software to analyse growth bands. Experienced readers to count growth bands are also necessary as growth band pairs are not always easily differentiable in specimens from tropical latitudes. These facilities are currently not available in PNG.

For species selected for age and growth work, frozen vertebrae were defrosted and cleaned. Vertebral centra were soaked in sodium hypochlorite to remove soft tissue, then rinsed and placed in a drying oven for 24hrs. Longitudinal sections of each centra were then made using a low-speed double bladed rotary saw with diamond-tipped blades. The vertebral sections were then mounted on glass slides for examination of growth bands. Sectioned vertebrae were examined under a dissecting microscope and individual ages were estimated by counting the number of opaque and translucent growth bands pairs proceeding the birthmark. Each opaque and translucent growth band pair was assumed to represent 1 year of growth in accordance with previous studies that have validated the timing of band pair deposition. Generally, opaque and translucent bands within a pair represent growth in summer and winter, respectively. Age estimation was carried out independently by 2 readers without knowledge of the sex or length of the individual. Results from readers were compared to detect bias, and final ages assigned through a consensus process. Ages were plotted against the total length of each specimen and various growth models (von Bertalanffy, Gompertz and logistic) were fitted using an information theoretic approach. A likelihood ratio test was used to determine whether growth of each sex was significantly different. Where growth was different between sexes growth models were calculated separately. If growth was not different between sexes, a combined sexes growth curve was calculated. Size and age at maturity was calculated by fitting logistic functions to maturity data collected by observers.

Age and growth work for key species was carried out by JCU staff and students.

5.6 Genetics

Shark and ray tissue samples from various activities were obtained during the project, e.g. sampled by observers on trawl and longline cruises; collected during artisanal fishery and village surveys – consisting of vertebrae, white muscle tissue, dried fin clips, or samples collected on Whatman FTA Elute cards. Some samples were kept frozen, others were preserved in absolute ethanol, while fins were usually kept dry. If ethanol was used to preserve tissues, we used printed waterproof paper labels (and or pencil labels) and inserted the labels into the sampling tube along with the tissue sample.

Each sample was accompanied by its' label/identifier and for many of the samples from the trawl and longline vessels, the observer's also supplied an image of the individual. The tissue samples were sent to the CSIRO marine laboratories in Hobart and were either stored frozen (and or preserved in absolute ethanol and frozen) at -80°C.

The various tissue samples were then DNA extracted. The extracted DNA was total genomic DNA which consists of both nuclear DNA and mitochondrial DNA (mtDNA). At each DNA extraction, sampling sheets (which contained the sample number and the sample well) were prepared prior to the extractions being undertaken. This further enabled all samples to be tracked throughout the laboratory processes.

5.6.1 Wizard SV DNA extraction protocol

For the majority of tissues, approximately 25mg of the tissues were DNA extracted according to a slightly modified Promega Wizard SV 96 well extraction protocol (https://au.promega.com/products/dna-and-rna-purification/genomic-dna-purification-kits/wizard-sv-96-genomic-dna-purification-system/; https://au.promega.com/resources/protocols/technical-bulletins/101/wizard-sv-96-genomic-dna-purification-system-protocol/). Briefly, the Wizard SV extraction protocol was based on a spin column format – the spin column contained a silica resin that selectively binds DNA depending on salt conditions. This extraction protocol provided the project team with a high throughput 96 well format for fast, simple preparation of intact, purified total DNA from the different tissue samples. DNA was eluted in water, with working stocks stored at 4°C and archival DNA stocks stored at -80°C. DNA was quantified on a

Nanodrop 8000 (UV-Vis Spectrophotometer) before being used for various genetic marker analyses.

5.6.2 Whatman FTA Elute DNA extraction protocol

During several village surveys, muscle and liver tissues from sharks and rays were sampled onto FTA Elute Cards (http://www.sigmaaldrich.com/catalog/product/aldrich/z747580?lang=en&region=AU) following the protocol provided (Appendix 9). The FTA Elute matrix is chemically treated with proprietary reagents (cellulose paper base impregnated with a surfactant, chelating agent, buffer and free radical trap) that lyse cells on contact and release nucleic acids. DNA is recovered from the FTA card through a simple elution process of water and heat. Inhibitory components are retained in the card matrix. Samples were collected and shipped at room temperature, without the need for ethanol preservation. Using a card punch, several punches were taken from the card and placed in microfuge tube, sterile water was added to the tube and the tube was then heated at 95°C for 1 hour. The DNA was eluted in the water, with a working stock stored at 4°C. DNA was quantified on a Nanodrop 8000 (UV-Vis Spectrophotometer) before being used for various genetic marker analyses.

5.6.3 Genetic marker development

The extracted DNA was used in number of downstream processes such as Polymerase Chain Reactions (PCR), sequencing and genotyping. Genetic markers such as microsatellites, single nucleotide polymorphisms (SNPS) and sequencing of mtDNA were utilised in the current project for the assessment of genetic connectivity among individuals, populations and species. Importantly, for the population genetic analyses, new microsatellite and SNP markers for silvertip sharks, grey reef sharks and scalloped hammerheads were developed in this project as there were few population genetic resources for these three species in the PNG region. As such, markers had to be developed and optimised prior to being deployed in each species. For the three species, microsatellite genotyping and mtDNA sequencing (Control Region and NADH dehydrogenase subunit 4) were undertaken at CSIRO, while the development and genotyping of SNPs was done at the Australian Genome Research Facility in Melbourne.

Additionally, sequencing specific areas of the mtDNA genome (e.g. cytochrome oxidase subunit 1 (COI) and NADH dehydrogenase subunit 2 (ND2)) was developed for DNA barcoding. Amplification of the mtDNA gene regions were undertaken using PCR (following optimisation trials for successful gene region amplification) with the resulting gene products cleaned and bi-directionally sequenced on DNA Autoanalysers. Resulting forward and reverse sequences were trimmed and checked and converted into consensus sequences using the program Geneious. The Barcode of Life Database (BOLD; http://www.boldsystems.org/) and GenBank (https://www.ncbi.nlm.nih.gov/nucleotide/) were used to check species identity based on the resulting sequences as a percentage of sequence identity.

Genetics research was carried out by CSIRO staff and a University of Tasmania/CSIRO PhD student, Madeline Green.

5.7 Stock assessment analyses

Demographic modelling of key species for which there are regional (PNG) life history parameters (collected during objective 1 of this project) was also conducted using a static age-structured Leslie Matrix model with a post-breeding census. This method is ideal for data poor species as it is only reliant on life history parameters. Natural mortality was estimated for those species using a range of indirect approaches including age independent and dependent equations, von Bertalanffy growth parameters and species-specific maturity indices. Demographic analyses were carried out for females as it was assumed that ample males were available for mating in shark populations. Monte Carlo simulations were used to stochastically vary specific vital rates and incorporate uncertainty into the matrix projections and resulting demographic parameters. Elasticity analysis was used to identify ages where changes to survival and age-specific fertility would most affect the finite rate of population growth, which is valuable information for conservation and management. Demographic parameters calculated include population growth rate, reproductive rate and generation time. Elasticity's were calculated for fertility, juvenile survival and adult survival. Various fisheries management scenarios were then examined and compared, i.e. applying two different harvest strategies: 1) age-at-first-capture – where juveniles are excluded for the fishery; 2) age-at-last-capture – gauntlet fisheries where juveniles are harvested while breeding stock is protected. Potentially sustainable harvest strategies identified in this process were explored further.

The demographic modelling was led by JCU with collaboration with NFA and CSIRO.

Two stock assessment/management options workshops were conducted during the project to discuss the outputs of these demographic analysis. In the final workshop, management options for NFA were discussed and viable options developed based on the findings of this project.

5.8 Shark and ray collection

PNG's national fish collection is located at the University of Papua New Guinea in Port Moresby (ex Kanudi collection) in a run-down old teaching building. All shark and ray specimens present in the collection were examined, measured, photographed and re-identified. The collection houses a large number of shark jaws and sawfish rostra which were in very poor condition when first examined, being all placed on top of each other in an empty glass aquarium. All jaws and rostra were cleaned, photographed, re-identified, re-labelled and placed on shelves in a compactus where they could not be damaged. A number of ethanol/formalin preserved specimens of sharks and rays were present in 30 L drums, many of which were damaged and some contained no fluid. All drums, including about 20 with bony fish, were replaced throughout the project and filled with clean 70% ethanol.

A number of large containers, including a small rainwater tank, a 500L plastic tank on a trolley, five 60L drums and two 100L cool boxes were introduced into the collection to enable fixation of more shark and ray material to add to the collection from this project. Approximately 400 specimens of sharks and rays were retained whole throughout the project, mostly from the prawn trawl and coastal fisheries surveys. Of these specimens, ~150 were registered and incorporated into the UPNG fish collection while the remaining specimens were deposited in the Australian National Fish Collection at CSIRO in Hobart. The deposition of material into both the UPNG and Hobart collections will ensure longevity of this important biological collection by duplicating species records.

A small workshop was held in 2016 to improve the existing collection. New drums (~20) and jars (>500) were brought and more than 400 L of clean ethanol were used to revitalise a portion of the collection.

The fish collection work was conducted by CSIRO, UPNG and NFA.

5.9 Biodiversity work

A list of all species verified from PNG was established throughout this project. In each case, the level of confidence and validation of each species was recorded. The vast majority of species could be verified as occurring in PNG waters by examining a wide range of sources, including:

- Museum specimens in the various biological collections around the world. All shark and ray museum specimens deposited in biological collections were either sighted or photographs obtained in order to verify;
- Literature records containing ample information for verification (rare for PNG specimens);
- Specimens observed or collected during this project;
- Photographs from observers or field enumerators during this project.

The final verified species list was used as a basis to develop a shark and ray field guide for PNG. The field guide includes images, and information on key features, size, distribution, colour, habitat and biology, international conservation status, for each of the species. A key to the families and genera was also produced and a guide to identification of dried shark and ray first dorsal fins and caudal fins was also incorporated into the field guide.

The biodiversity research and book was authored by CSIRO, UPNG and NFA.

6 Achievements against activities and outputs/milestones

Objective 1: Describe the biological, socioeconomic, catch and gear characteristics of the fisheries exploiting shark and ray resources

no.	activity	outputs/ milestones	completion date	comments
1.1	Training observers on biological data collection and species identification	Training workshops for fisheries observers who will be on the tuna, shark and shrimp fishery boats. Guides and keys to species encountered and protocol guides for biological data collection *(A [CSIRO staff] and PC [NFA staff, observers])*	Mar 2014	The training workshops for observers on longline boats and prawn trawlers were held in mid-March 2014 in Port Moresby; observers were trained in data collection requirements. The longline observers in Rabaul were also trained in the same week. Overall, approximately 25 observers were involved in these workshops and there was very positive feedback regarding the training provided. Two manuals (longline – Appendix 1, and prawn trawl – Appendix 2), which each included species identification guides, were developed and printed for the workshops and handed out to each observer.
1.2	Collect, collate and analyse observer data from the key fisheries	Observer database for catch composition and biological data for the major shark fisheries – shark and tuna longline and purse seine fisheries *(A [CSIRO] and PC [NFA])*	April 2014-April 2016	**Data collection** Draft data sheets (modified from the currently used Secretariat of the Pacific Community, SPC, LL-4 forms) were designed for both the longline (Appendix 3) and trawl (Appendix 4) fisheries prior to the March workshops and then refined based on feedback during the workshops. The CSIRO/NFA/ACIAR Shark and Ray Database was developed in Access in August 2014. Longline and trawl entry forms and a large number of tables (e.g. catch details, cruise details, species codes, gear setting details) and queries form the basis of this relational database in which all shark and ray data has been entered. The database contains catch, gear set, and biological data for the 7 target shark longline, 10 tuna longline and 7 prawn trawl observer trips. It also houses data from the various coastal survey trips and several opportunistic data sources. It includes 963 data events (i.e. trawl set, longline set, village survey, etc.) and more than 18,000 individual specimen records. The database is currently housed at CSIRO with a final copy to be delivered to NFA at end of project. **Data analyses** The observer data for the prawn trawl, tuna longline and shark longline fisheries have been analysed to produce accurate catch composition data and CPUE estimates. These are discussed in sections 7.3, 7.4 and 7.8 below.

		Acquisition of tissue samples from key species by observers *(A [CSIRO] and PC [observers])*	April 2014-April 2016	Over 3000 traceable muscle and fin clip tissues (sampled from mostly photographed sharks and rays) have been collected with corresponding metadata. These tissue samples are stored in absolute ethanol and maintained in -80° C freezers in Hobart for archival purposes, DNA extraction and genetic studies. A plain language sampling guide for Whatman FTA Elute cards was also developed (Appendix 9) to provide to potential enumerators in the field for collecting tissue samples without needing vials of preservatives. During the Western Province coastal fisheries survey in October 2014, the sampling guide and FTA Elute cards were given to the village chairman in Katatai (Jagara Page) to enable genetic samples of sharks and rays to be taken and stored, without the need for ethanol or freezer capacity. The cards were sent back to the CSIRO labs and stored at room temperature. DNA was extracted from the FTA Elute cards. The DNA is used in genetic species identifications.
1.3	Determine key species in the longline fisheries and undertake age and growth studies on several of these species	Collection of vertebrae from the most abundant species for age and growth studies *(A [CSIRO and JCU] and PC [NFA, observers])*	April 2014-April 2016	In May 2014, observers were deployed on 7 target shark longline boats operating out of Rabaul (8 week trips). The longline guides (from Activity 1.1) were given to the observers which include the 6 key shark species for vertebral collection. A total of 1040 vertebral samples from 18 shark species were retained, of which 910 of these were from one of the 6 key shark species. Between May 2015 and October 2016, observers were deployed on 10 tuna longline fishing trips operating out of Port Moresby. A total of 139 vertebral samples were obtained, the majority from one of the key species. Between June 2014 and September 2016, observers were deployed on 7 prawn trawl trips operating in the Gulf of Papua. A total of 747 vertebrae were retained from the observer samples. Most samples were not from key species but those from the most abundant shark species were used for the JAF student (Leontine Baje) PhD project. Several vertebrae from 3 shark species and 2 ray species were also collected by the Katatai village chairman in Daru. Thus about 2000 vertebral samples were collected during this project, all with traceable metadata and from key or abundant species in the various fisheries.
		Population-based age and growth data for the key species *(A [JCU, CSIRO])*	Dec 2016	A PhD student at JCU (Jonathan Smart) has completed his work on the age and growth of two of the key species, the grey reef shark *Carcharhinus amblyrhynchos* (Appendix 10) and the silvertip shark *Carcharhinus albimarginatus* (Appendix 11). A student at JCU (Brooke D'Alberto) has completed a Masters project on the age and growth of another key species, the oceanic whitetip shark *Carcharhinus*

				longimanus (Appendix 12). Brooke is currently finalising age and growth determination in the scalloped hammerhead *Sphyrna lewini*. She is currently assisting another JCU Masters student, Sushmita Mukherji on the age and growth of the thresher sharks *Alopias pelagicus* and *A. superciliosus*, and the blue shark *Prionace glauca*. Sushmita has finalised the blue shark age and growth and this work is currently being prepared for publication. Another JCU student (Michael Grant) completed an Honours project on the age and growth of the most important key species, the silky shark *Carcharhinus falciformis* (Appendix 13). The above species represent the most important key species in the PNG longline fisheries. The successful John Allwright Fellowship (JAF) candidate (Leontine Baje), who commenced at JCU in July 2015 and upgraded her Masters to PhD in 2017, is undertaking age and growth determination on the two most abundant shark species out of the prawn trawl bycatch, i.e. the Australian sharpnose shark *Rhizoprionodon taylori* and whitecheek shark *Carcharhinus coatesi*. The results for the former species are currently in review (Appendix 14) and for the latter species are due for impending submission (Appendix 15).
1.4	Investigate species composition of coastal artisanal fisheries and the shrimp trawl fishery	Biodiversity information collected from small-scale coastal fisheries and shrimp trawl fishery *(A [CSIRO] and PC [NFA])*	Mar 2016	**Trawl fishery** During the observer program for the prawn trawl fishery, between June 2014 and September 2016, observers retained all small specimens of sharks and rays and photographed, measured and took genetic samples from all large specimens that were not retained. Thus, we were able to obtain 100% verification of species identifications through this process and a record of all sharks and rays caught in each trawl shot. A total of 41 species of sharks (18) and rays (23) have been recorded to date, several of which are new records for PNG waters. The trawl data included data for 2030 individual sharks and rays equivalent to ~4.34 tonnes. The results from the trawl observer work has been analysed and drafted as a paper due to be submitted soon to *Fisheries Research* (see Appendix 16 for key tables and figures). Leontine Baje (JAF student) is currently undertaking an Ecological Risk Assessment for sharks and rays in the Gulf of Papua as part of her PhD. **Coastal fisheries surveys** Shark and ray catches, either whole specimens or parts (e.g. fins, jaws, rostra), were recorded during each of the coastal fisheries surveys. Enumerators were established where possible, either short term (e.g. over several days during our trip) or longer term (e.g. for several weeks or

				more following a trip). A total of 1164 individuals representing 49 species of sharks and rays were recorded during the coastal fisheries surveys. A large number of these were from dried fins in which case DNA barcoding was typically used to determine species identities. The first coastal fisheries trip was conducted in October 2014 to Daru region in the Western Province. Although shark and ray catches were low, very useful biodiversity information was collected. In particular, 4 species of sawfish (Pristidae) and 2 species of river shark (*Glyphis*) were recorded. The latter records were the first confirmed records of these species from PNG in over 40 years. The river shark data was published in *PLoS One* (Appendix 17). The sawfish data from this trip was combined with all other sawfish data from this project, combined with historical data and published (Appendix 18). The second coastal fisheries survey trip was conducted in October 2015 to Kavieng in New Ireland and Buka in Bougainville. Shark and ray catches were low (but reflective of the true situation), but some very useful biodiversity information was collected. The third coastal fisheries survey trip was conducted in March 2016 to Milne Bay province. Catches of sharks were highest in this area and thus a large number of dried fins were observed. A total of 640 dried fins were sampled during this trip. This large fin batch was used to test the use of dried fins as surrogate information for characterising the catches of various regions in PNG. The results from this Milne Bay fin data have been produced as a journal article in *Scientific Reports* (Appendix 19). The fourth and final coastal fisheries survey trip was conducted in the East Sepik region. A large amount of shark and ray data was collected, particularly at the mouth of the Sepik River. An enumerator was established to continue to collect data if possible.
1.5	Assess economic status and social characteristics of smallholders dependent on shark fisheries	Collection of socioeconomic data from the major fisheries, coastal artisanal fisheries and possibly ecotourism activities, e.g. dive operators *(A [Vieira] and PC [NFA])*	Feb 2014-Sep 2015	The first socio-economic data collection trip was conducted in February 2014 in Port Moresby. The trip focused on obtaining intra-provincial trade data (particularly for shark fin), shark product export data (quantities and prices), and catch and effort data for relevant fisheries. These data combined provide an indication of the economic benefits generated by shark resources for PNG. Interviews were also conducted with relevant large scale fishery operators (shark longline, prawn trawl). The second socio-economic survey trip was conducted in the Milne Bay Province in November 2014. Just under a week was spent on Brooker Island and visiting surrounding islands in the Louisiade Archipelago. Interviews and focus group discussions were held with shark fishers,

				small-scale buyers of shark fin and community leaders to gain an understanding of the local shark fishery. Fishers here practice shark finning. Income from the sale of fin drives shark targeting behaviour and is one of the few sources of income for communities in the area. The provincial capital of Alotau was also visited during this trip. It is the main market destination and point of export for locally produced shark fin. Discussions were held with two exporting companies and a large amount of data on purchases of shark fin and other income providing marine resource commodities were obtained. The third socio-economic data collection trip was conducted in October 2015 to Kavieng in New Ireland and Manus. Just under a week was spent in both locations. Interviews and focus group discussions were held with shark fishers, small-scale buyers of shark fin and community leaders to gain an understanding of the local shark fishery. Fishers in these areas currently do not rely heavily on shark finning and thus it was not a common practice. A reduction in the number of shark fin buyers in both locations (largely due to the sea cucumber ban) has been a contributing factor.
		Report on economic status and social characteristics of shark fisheries *(A [Vieira] and PC [NFA])*	Mar 2017	The data collected from the Milne Bay survey trip were evaluated to assess economic status and social characteristics of local artisanal shark fisheries and to inform the identification of potential management options to improve resource sustainability and the economic benefits derived from local livelihoods. The results were presented in the journal paper *Oceans & Coastal Development* (Appendix 20). A report summarising the available data collected and maintained by NFA relevant to shark fishing in PNG has been developed (Appendix 21) and is currently being modified into a journal paper. Its findings provide an indication of the economic benefits generated by PNG's shark resources.
1.6	Collect information on shark and ray observations from the dive industry	A diver observation database and biodiversity information *(A [CSIRO] and PC [NFA])*	Dec 2016	A guide to the sharks and rays that could possibly be encountered in PNG was developed (Appendix 8). This included a specimen image (book quality) as well as an underwater photograph of potential species. These guides were distributed to the various dive companies visited. In addition, a Facebook page was created and a one-page information sheet produced (Appendix 7) and distributed to relevant dive related places or people to enable collection of shark and ray sighting information. The Facebook page had no uptake, partly due to lack of time to maintain and update so was not used beyond the first year of the project. Direct contact with divers was considered more important. During the coastal fisheries surveys, meetings were held with the local dive

				companies where possible. These include, Scuba Kavieng (Dorian Borcherds) and Lissenung Island Retreat (Dietmar Amom) in New Ireland; Tawali Dive Resort (Alfred George) in Milne Bay; Kabaira Dive (Stephen Woolcott *late*) in East New Britain; and Loloata Island (Dik Knight) in Port Moresby. In addition, the Walindi Plantation Resort and Dive (Max and Cheyne Benjamin) were also contacted via email and communication established. All but one of the above contacts provided a biodiversity information and supporting images of sharks and rays they have observed in their respective regions. A number of these are new records for PNG. Email and phone contact was also made with Bob Halstead in 2016 who pioneered much of the diving in PNG and he provided some additional information and a large number of images for the book (objective 3.3 below). Mark Erdmann and Gerry Allen are colleagues of W. White and also provided underwater images from PNG to the project for the biodiversity components.

PC = partner country, A = Australia

Objective 2: Assess the status of the stocks of key species and determine the extent to which they are or could be shared with Australia and Indonesia and advise on necessary changes to current management plans

no.	activity	outputs/ milestones	completion date	comments
2.1	Face-to-face meetings, informal workshops on basic training on population genetic analyses	Protocol guides and basic training of staff on genetic techniques *(A [CSIRO] and PC [NFA])*	Aug 2014-Dec 2016	During a three-week taxonomy and genetic workshop (see more details in 3.1 below), detailed information was provided on practical genetics for shark and ray monitoring, and an overview of the DNA barcoding process (including DNA extractions, PCRs and sequencing for species identifications). The use of the international BOLD database was discussed and highlighted as a tool for future uptake via PNG project staff. A Crawford Fund project, entitled “Age and growth determination in fishes and curatorial training for museum collections” supported a workshop held in Hobart in March 2017 where the processes and equipment involved in genetic studies were highlighted to an established UPNG staff member and a prospective student. The final report for this can be found in Appendix 22). Results from genetic analysis of the tissue samples obtained from the deepwater trawl surveys conducted on the French vessel FRV *Alis* were discussed with Ralph Mana at UPNG to highlight the importance of genetic techniques for species verification and for highlighting where cryptic speciation may be present. Five new species description papers resulting from this work were published (Appendices 23-27), several of which included Dr Mana as an author and one was named after Dr Mana

				(*Rhinobatos manai*, Appendix 23). Due to staffing issues at NFA during the latter half of the project, no PNG staff were allocated for basic population genetic training. Instead, more emphasis was placed on obtaining detailed population genetic data (see 2.2 below).
2.2	Undertake population genetic studies to determine whether populations of 1-2 key exploited shark species are shared	Establish a tissue collection of key shark species. New molecular markers for exploited shark species. Training in bioinformatics and population genetic analyses *(A [CSIRO, UTAS] and PC [NFA])*	Feb 2017	Madeline Green (UTas PhD student) was selected as a PhD candidate for this objective and commenced in March 2015. Her thesis is titled – 'Population connectivity of sharks in the western South Pacific'. Three species were selected for developing and deploying population markers: the scalloped hammerhead, grey reef shark and silver tip shark. In addition, genetic samples obtained from litters and mothers for two of these species (scalloped hammerhead and grey reef shark) were used to explore multiple paternity in those species. For each species; scalloped hammerhead, silvertip shark and grey reef shark 338, 98 and 447 samples were collected from PNG respectively. Samples from other locations across the Indo-West Pacific were also obtained in order to better understand and compare population structure within and around the PNG region. DNA from samples was extracted (see above for extraction protocols) and used for three different genetic methods for population analyses. MtDNA, microsatellites and novel genome wide SNPs were used to assess the population structure and connectivity for species throughout the PNG and broader Indo-Pacific region. To date, the genetic findings suggest: • population connectivity for silvertip and grey reef sharks between Australia, Indonesia and Papua New Guinea - it is strongly considered that the identified genetic connectivity is facilitated by male biased dispersal in the two species
		Scientific publication(s) on the extent to which key shark species are shared, new (?) publically available molecular markers for sharks *(A [CSIRO, UTAS] and PC [NFA])*	March 2017	Inclusion of samples from narrow sawfish *Anoxypristis cuspidata* collected from the trawl bycatch and coastal fisheries surveys were incorporated into a project previously undertaken by Madi Green at JCU. The PNG samples made the analyses more robust and strengthened the results of the study which was recently accepted in *Endangered Species Research* (Appendix 28). Multiple paternity in 6 grey reef shark and 5 scalloped hammerhead litters analysed using the optimised microsatellite loci. Results were published *Scientific Reports* (Appendix 29) and presented (oral) at the joint conference of Australian Society of Fish Biology & Oceania Chondrichthyan Society 2016 September, Hobart. Three journal publications are currently being prepared based on the findings of the population structure components, one for

				each of the species investigated. On completion (June 2018), manuscripts will be submitted to journals such as *Nature Heredity*, *Marine Ecology Progress Series* and *Fisheries Research* (see Appendix 30 for key result figures for each species).
2.3	Assess stocks of key target shark species	Stock assessments for key species *(A [JCU, CSIRO] and PC [NFA])*	Mar 2017	**Demographic analyses** Stochastic demographic analyses were conducted on the silvertip shark by J. Smart during his PhD (Appendix 31). Jon Smart and M. Grant are currently working on a publication investigating the intraspecific demographic variation of the silky shark throughout its global range. Demographic models are currently also being developed for 6 more key shark species (silky shark, blue shark, oceanic whitetip shark, scalloped hammerhead, pelagic thresher, bigeye thresher) and are planned to be published as a single journal article in the coming months on demography of pelagic sharks from PNG. **Stock assessment workshops** A stock assessment workshop was originally planned for November 2016 but was cancelled at the last minute. Subsequent locking in of dates for this workshop to be held in Port Moresby failed to happen. The workshop was finally combined with the final workshop held in Hobart in January 2018, unfortunately with only one NFA staff member available.
		Development of management options for sustainable use of shark and ray resources in PNG *(A [CSIRO, Vieira, JCU] and PC [PNG])*	Apr 2017	During the final workshop in Hobart in January 2018, possible management options for NFA to consider to ensure sustainable use PNGs shark and ray resources were developed. These management options were summarised in an ACIAR Policy Brief (Appendix 32).

PC = partner country, A = Australia

Objective 3: Develop a well-maintained biological collection and technical tools to facilitate management and conservation of shark and ray resources

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	Establish a shark and ray collection and improve functioning of an existing fish collection	Training workshop conducted for an NFA staff member *(A [CSIRO] and PC [NFA, UPNG])*	Sep 2014	**Taxonomy and genetic training workshop** In September 2014, a three-week taxonomic and population genetics training workshop was held at CSIRO Hobart. Leontine Baje from NFA participated in this 'train-the-trainer' workshop which provided detailed information on basic taxonomic techniques and an introduction to practical genetics for shark and ray monitoring. A protocol guide for basic taxonomic collection and genetic techniques was

				developed (Appendix 33). The final week involved participation in a description of a new species of eagle ray from northern Australia and PNG. This work was published in the journal *Ichthyological Research* (Appendix 34).
		A well-maintained and functioning shark and ray collection within an upgraded, pre-existing fish collection *(A [CSIRO] and PC [NFA, UPNG])*	Nov 2016	**Shark and ray collection** 322 specimens of sharks and rays were obtained during this project. A total of 170 of these specimens were deposited in the KFRS collection at UPNG and were allocated new registration numbers in line with the current registration scheme (following discussion with Alfred Ko'ou, UPNG). The remaining specimens were deposited in the Australian National Fish Collection (CSIRO) in Hobart to ensure a duplicate collection exists. The new collection of sharks and rays doubled the existing shark and ray collection. However, many of the specimens already present in the collection were poor quality and often had limited metadata attached (e.g. date, collector, location of capture). The new specimens were all high quality with associated metadata and mostly with genetic samples linked to them. **Upgrade of existing collection** Improvements were made to the existing collection (in general, not only for the shark and ray component) throughout the project. Most notably, a workshop in August 2016 focused on replacing old and damaged storage containers (drums and jars) with new ones. Over 500 new jars were brought into the collection to replace older jars; more than 20 new 30L or 60L plastic drums for larger specimens were replaced; and a large (500L) plastic container with trolley was donated by the ANFC to the UPNG collection for the larger shark and ray specimens. In addition to the shark and ray collection, the jars of teleost fishes were also examined to determine if the specimen was 1) ok, 2) low on alcohol (topped up if so), 3) if jar needed replacing. During the workshop, we made it only less than a quarter through the collection so more work is needed during future trips or projects to complete this inventory. Close to 200 specimens could not be saved and have been marked down as destroyed. More than 800L of clean ethanol was used during the upgrade process and an additional approximately 300L of clean ethanol was left with the collection at the end of the project. Several large containers for 10% formalin were also left with the collection for fixation of specimens prior to being stepped up into 70% ethanol for longer term storage. Formalin is a carcinogenic product so we ensured that all specimens collected by the

				project had been removed from formalin, stepped up (washing process) and then placed into 70% ethanol for longer term and safer storage. Subsequent to our upgrading work, UPNG obtained some funds from NFA to do further cleaning and upgrading of the fish collection (see Appendix 35). **Other PNG specimens in museums** During trips to international museum collections by W. White as part of a separate National Science Foundation (NSF) funded shark and ray project (Chondrichthyan Tree of Life), all specimens of sharks and rays collected from PNG waters were examined and inventoried. Images and measurements from specimens in other museums not visited were also obtained to provide full coverage. **Overall biodiversity of sharks and rays** The combined work on the PNG specimens in collections, together with other components of this project, allowed us to have a complete record of all shark and ray specimens collected in PNG waters since the first specimens collected in 1825. This information is summarised in a checklist of sharks and rays in PNG (Appendix 36).
3.2	Develop a DNA barcoding capability, including molecular sequencing and analysis skills	A selected PNG scientist to become an active participant in Barcode of Life Database (BOLD) project *(A [CSIRO] and PC [NFA])*	Feb 2016	For ongoing in-country barcoding at the completion of the current project, NFA (and/or UPNG) requires access to in-country and or dedicated PNG barcoding trained personnel. As yet, NFA has not identified a PNG scientist to take on the genetic/BOLD barcoding activities (i.e. an in-country project leader has not been identified). Leontine Baje was trained in DNA barcoding techniques during the September 2014 taxonomy and genetics workshop. She subsequently moved to Townsville for her JAF scholarship and will be there until 2018. Leontine is the best placed person to potentially become a participant in the BOLD project if NFA agrees it is beneficial for future research. Alternatively, a UPNG staff member (Alfred Ko'ou, Ralph Mana etc.) may be worth consulting in the future if the need is ongoing. Additional training in barcoding quality controls, consensus sequence generation and data uploads to BOLD are required if and when NFA identifies an in-country BOLD project leader.
		Quality controlled sequence data from PNG sharks and rays submitted to global barcoding database *(A [CSIRO] and PC [NFA])*	Feb 2017	Genetic barcoding for the project was carried at the CSIRO laboratories in Hobart. Additional sequencing (no cost to project) was provided by the College of Charleston through an NSF-funded project. During the project, over 1 400 genetic identifications using DNA barcoding (based on multiple mtDNA gene regions, e.g., COI,

				ND2, 16S rRNA) were undertaken to confirm/resolve species identifications and to obtain biodiversity and biogeography data primarily from the observer program and from the artisanal surveys. Genetic samples were obtained from various activities of this project, e.g., from prawn trawl and longline vessels, coastal fisheries surveys and opportunistically. Examples where species identification verification was required in the current project were: • samples from longline observers (Objective 1.2 and Objective 1.3) where the photographs taken were not adequate to unambiguously identify the specimen; • dried (rarely fresh) fin samples (Objective 1.4) where only a first dorsal or caudal fin was observed preventing accurate species identification; • trawl or coastal fisheries samples (Objective 1.4) where the species could not be accurately identified from the photographs, or the species in question was difficult to confirm from only a photograph (e.g., the reticulate whiprays), or confirming that PNG specimens are in fact the same species as specimens from other countries (e.g. in some ray species); • when representatives of a particular species have not been previously DNA barcoded and thus were not present in the genetic sequence libraries available for comparisons, i.e., used to populate international databases if required (Objective 3.2). A Crawford Fund project, entitled “Age and growth determination in fishes and curatorial training for museum collections” supported a workshop held in Hobart in March 2017 where the processes and equipment involved in genetic studies were highlighted to UPNG staff (Appendix 22). **COI sequencing** A significant component of the genetic analyses, COI barcoding (approximately 650bp) was undertaken at the genetics laboratory at CSIRO Marine Laboratories in Hobart. Over 400 samples from the longline fishery (species confirmation when photography was not adequate for identification) and over 700 samples of dried fins (e.g. Appendix 19) were amplified and sequenced, although some samples from the trawl and coastal fisheries surveys were also included (particularly when species verification was required). Verified species identifications for each sample were uploaded to the CSIRO/ACIAR/NFA database. Representative COI sequences from species identified in PNG (based on samples from this project that are included in manuscripts) have been deposited in GenBank (www.ncbi.nlm.nih.gov/genbank).

				A large number of new sequencing records for specimens from PNG will also be available within the BOLD project SOPNG 'Sharks and rays of PNG', http://www.barcodinglife.com/). This project consists of approximately 170 sequences from PNG samples that have accompanying location specific metadata. **ND2 sequencing** For the mtDNA sequencing, ND2 (approximately 1 200 base pairs (bp)) was primarily analysed by Gavin Naylor's molecular laboratory at the College of Charleston (now at University of Florida, Gainesville), as part of a National Science Foundation project, i.e. Cartilaginous Tree of Life. Since the Tree of Life project required representatives of sharks and rays from the PNG region, samples from PNG were donated in return for sequence results. Through this process, several hundred samples were sequenced by the Tree of Life project, strongly adding to their significant database of samples and providing some no-cost DNA sequencing to the current project (see Objective 2.1). Since a requirement for this project was that samples needed to come from verified sources, i.e., be retained in museums or have good images of the whole animal, samples obtained from dried fins and from the longline observer program could not be sent.
		Scientific publication(s) on molecular species identifications of PNG sharks and rays *(A [CSIRO] and PC [NFA])*	Mar 2017	**Taxonomic research** COI and ND2 sequences from the following samples collected on this project were included in publications by project members: 1) new eagle ray *Aetomylaeus caeruleofasciatus*) from northern Australia and Gulf of Papua (Appendix 34); 2) new maskray *Neotrygon australiae* from eastern Indonesia, northern Australia and Western Province of PNG (Appendix 37); 3) new large whipray *Urogymnus acanthobothrium* from northern Australia and Gulf of Papua (Appendix 38); 4) new reticulate whipray *Himantura australis* from northern Australia and New Guinea (Appendix 39); 5) a new gulper shark *Centrophorus longipinnis* from the West Pacific (Appendix 40). Subsamples of the deepwater sharks and rays collected by the National Taiwan University Museum during 4 surveys of the deepwater of PNG (2010-2014) were obtained by W. White during a trip to Taiwan in January 2016. The ND2 sequences obtained from these samples were used in a number of taxonomic papers: 1) a new guitarfish *Rhinobatos manai* (Appendix 23); 2) a new sawtail catshark *Galeus corriganae* (Appendix 24); 3) a new velvet skate *Notoraja sereti* (Appendix 25); 4) a new lanternshark *Etmopterus samadiae* (Appendix 26); 5) a new catshark *Apristurus yangi* (Appendix 27); 6) redescription of *Chimaera ogilbyi*

				(Appendix 41). **Ecological or fisheries research** Barcode sequences from the two river sharks collected from Daru were included in a paper (Appendix 17). Identification of dried shark fins using DNA barcoding formed a large component of a coastal fisheries paper based on the Milne Bay case study. This paper is published in Nature's *Scientific Reports* (Appendix 19). Confirmation of species identifications (both ND2 and COI) from the trawl fisheries component are included in a publication on this fishery currently being finalised and due to be submitted to *Fisheries Research* in the next month (see Appendix 16 for figures and tables).
3.3	Develop a field guide to the sharks and rays of PNG	A field guide to sharks and rays of PNG *(A [CSIRO] and PC [NFA])*	June 2017	A proposal was submitted to ACIAR Publishing for the shark and ray field guide in early 2016 and this was approved in March 2016. Information for the book was collected throughout the project, with commencement of the book was in early 2017 and completion in late 2017. The book, entitled "*Sharks and Rays of Papua New Guinea*" was published in January 2018 (Appendix 42). About 200 copies of the book were distributed in the first week after publication, mostly to contributors to the book, stakeholders and relevant agencies in PNG and other interested parties. The key components of the book include: • Key to families and genera of sharks in PNG; • Species profiles for all 132 species confirmed from PNG; • A checklist of all species; • A guide to identification of dried dorsal and caudal fins in PNG.

PC = partner country, A = Australia

7 Key results and discussion

7.1 Fisheries observer program

Key results

- Detailed catch data was collected from target shark longline, tuna longline and prawn trawl vessels;
- More than 1000 vertebrae and genetic samples from key shark species collected in the first 6 months of the project.

Discussion

In March 2014, four weeks after the inception meeting and launch of the project, a training workshop for NFA observers was carried out in both Port Moresby (longline and trawl observers) and Rabaul (longline observers). A data collection protocol and species identification guide was produced for both the longline fisheries (Appendix 1) and trawl fishery (Appendix 2). The workshops foci were to inform observers likely to be used in the project's observer program of the shark specific data requirements and the importance of traceability of any samples retained (e.g. vertebrae and genetic samples).

The NFA observers present at the workshops were all SPC trained and experienced observers which ensured the workshops ran very smoothly and much quicker than anticipated. Observers informed us that the additional data requirements we were requesting would be easily achievable. The Rabaul workshop was particularly useful as a number of observers had just returned from a previous observing trip and understood the additional requirements more so than observers who had not been to sea recently.

In May 2014, 6 weeks after the observer training, 7 observers were sent out on 7 of the 8 target shark longline vessels deployed from Rabaul. These fishing trips lasted 2 months and while data quality varied between observers, the data collected was much better quality than we had anticipated. In particular, over 1000 vertebrae were collected between the observers from key shark species. This exceeded our expectations and enabled the life history and age and growth components of the project to commence much earlier than planned. The quick planning and deployment of observers by NFA made this possible.

In July 2014, the target longline fishery was closed due to WCPFC classifying silky sharks as a no-take species (already the case for oceanic whitetips); silky sharks were a key species in this fishery. The large number of samples from the observers thus proved to be more important as additional samples from some key species could not be collected again.

Observers were also deployed on 7 trawl vessel trips (commencing June 2014) and on 10 tuna longline trips (commencing May 2015). The prawn trawl observers were exemplary, allowing for 100% verification of all sharks and rays observed in all sets recorded. This feat is rarely accomplished in any country and further supports the high quality of observers that NFA has.

The tuna longline observer program took longer to commence due to lack of response/resistance from Fairwell Investments who owns the fleet. Continued pressure from NFA ensured this component went ahead and achieved what was set out in the original proposal. The observer data was again of high quality.

NFA should continue to retain the high-quality observers they have trained and deploy them to their full potential. Observer coverage is low to almost none in some fisheries (tuna longline and trawl) and this project highlights the benefits of having good observer coverage.

7.2 Accuracy of species identification by longline observers

Key results

- Levels of species misidentification in the shark longline observer data was investigated;
- Misidentifications not reflective of observer quality in most cases, rather highlights the difficulty in identifying some sharks species;
- Region-specific identification tools required

Discussion

Of the ~14,000 sharks recorded by the shark longline observers, vertebrae were collected from 1040 sharks. The identifications of all sharks with vertebrae retained could be verified by either images taken by the observers or by subsequent DNA barcoding at CSIRO in Hobart. Thus, the level of misidentification could be explored within that subset of samples.

Overall, most sharks were identified correctly by the observers, again reflecting the high quality of NFA observers in PNG. Of the 1040 verifiable sharks, the identities of 87 (8%) were changed based on images of those specimens, and 33 (3%) were changed based on subsequent DNA barcoding. When exploring the misidentifications, it became apparent that the pattern of misidentification differed between observers. For example, several observers had no misidentifications and some observers only misidentified a certain species and not others.

Although the level of misidentification in the longline data was overall relatively low (~11%), it should still be considered an issue needing to be resolved. Out of the 14,000 sharks recorded, this would equate to ~1500 sharks being misidentified.

Overall, silky sharks were misidentified as 6 other species within the verifiable data. A number of bronze whaler and Galapagos sharks were recorded (almost exclusively by a single observer), but all verifiable records proved to be silky sharks. Thus, the ~300 records of this species in the non-verifiable data could be assumed to be silky sharks. However, a number of sharks identified as grey reef sharks proved to be silky sharks, but grey reef sharks were also verified from the catches; thus, no assumptions could be made from the non-verifiable data.

Misidentifications were also either apparent or of potential concern from within the non-verifiable data. For example, the longfin mako was recorded 15 times in the shark longline data. Although an easily identifiable species, records in the tuna longline data of this species proved to be blue sharks. Thus, concern over their validity must be raised. Blacktip reef sharks were also recorded by some observers but their large sizes confirms they are not that species.

These results highlighted the need for regional specific identification guides, particularly at a fisheries level. The SPC trained observers were equipped with and used regional guides. Although these guides are good, they do include some species not found in PNG waters and as a result were a source of misidentification. Specific identification tools for each fishery would overcome some of the misidentification problems.

Smart *et al*. (2016, Appendix 10) investigated how misidentifications could introduce errors in a species' life history parameters if undetected. This highlighted the importance of species validation during this project.

The level of misidentification in the trawl fishery was far higher but this reflects the high diversity of sharks and rays in the fishing grounds that are poorly known and can be readily confused. Ideally NFA will expand its observer program in the trawl fishery which will require training around species identification and access to adequate tools.

7.3 Shark catches in the shark longline fishery

Key results

- A total of 18 shark species caught in this fishery, with the silky shark constituting 87% of the catch by number and 81% of the catch by weight;
- From the observer data from one trip on 6 of the 8 longline vessels operating, the total estimated biomass of the shark catch was 439 tonnes with a CPUE of 42.5 sharks per thousand hooks;
- Silky sharks dominated the catch in all regions, often representing >90% of the catch.

Discussion

The observer program adopted for this project, using trained NFA observers had a strong emphasis on this fishery due to the targeting of sharks and the known high catch rates. This fishery was closed however in July 2014. Fortuitously, we had undertaken our observer training workshops early in the first year and were able to have 7 observers out on the final fishing trips of this fishery. The closure of the fishery was due to a ‘no-take’ policy for silky sharks *Carcharhinus falciformis* from the WCPFC following stock assessment analysis for this species in the region.

The observer fishing trips covered a wide geographic range through much of PNG (except the Coral Sea) and allowed for detailed comparisons of the catch composition throughout the area. Catch-per-unit-effort (CPUE, sharks per ‘000 hooks) was greatest in the northern Bismarck Archipelago, from the Nigoherm Islands (west of Manus) to northeastern New Ireland (Appendix 43). The lowest CPUE’s were reported from the eastern Bismarck Sea and central Solomon Sea. In all regions, silky sharks strongly dominated the catch, sometimes in excess of 95% of the catch (Appendix 43).

The catches of a number of species showed clear regional variation. For example, grey reef sharks *Carcharhinus amblyrhynchos*, were mostly caught in the Milne Bay, Bougainville and southeastern New Ireland regions. In general, the Solomon Islands area, consisted of more diverse catches. In particular, the southern Milne Bay region had the lowest contribution of silky sharks (66%) due to the higher catches of other species, some of which were rarely caught in the Bismarck Sea regions (Appendix 43).

The size and sex composition data for the key species also revealed some important information which should be considered in future management options for this fishery (if reopened). The dominance of juveniles in the catches for most species is an important characteristic of this fishery.

One of the main findings of this component was the high overlap between the catch composition of this fishery and that of coastal fisheries. Thus, management measures for this fishery should include implications of the interaction with coastal fisheries. Although catches in the coastal fisheries sector are far less, coastal communities have a far greater number of livelihoods to consider with less alternative livelihood options. This highlights the need for a holistic approach to manage PNG’s shark fisheries.

7.4 Shark bycatch in the tuna longline fishery

Key results

- A total of 10 shark species and a single ray species were caught as bycatch in this fishery, with the silky shark and blue shark constituting 47 and 36%, respectively, to the catch by number and 43 and 31% of the catch by weight, respectively;
- The total catch from the 10 observer trips had an estimated biomass of 9.7 tonnes with an average weight of 67.8 kg per shark (range 1.8 to 261 kg);
- The CPUE from the data collected across all observer trips was 6.5 sharks per 1000 hooks, far less than the 42.5 sharks per 1000 hooks in the target longline fishery.

Discussion

The observer trips for this fishery took over 12 months to commence from the onset of the observer program for the project. This was the result of non-compliance with the fishing company which was resolved in 2015 and observers were placed on the vessels.

The Tuna Management Plan (Anon. 2014) states, in relation to sharks, “Longline operations may retain bycatch including non-endangered sharks, subject to any license conditions and with all fins attached to trunks. The possession of shark fins removed from any trunk shall be a breach of this Plan.” Shark species such as silky sharks and oceanic whitetips would presumably not be categorised as “non-endangered” but that is not explicitly stated. During the fishing trips, observers stated that finning did not occur during their observing. However, one observer stated that when discussing fishing activities with the crew, they informed him that sharks are not finned when observers are on-board but finning does occur when there are no observers on-board. This was said to occur on all vessels within that company. This suggests a potential enforcement issue as there is likely to be clear breaching of the management plan.

A further issue which needs consideration is the survivability of the sharks following capture if the vessels were fully compliant with the management plan. From the observer data, 36% of the sharks caught were dead or dying when brought to the boat. About 70% of sharks were dead when discarded.

Based on the above findings, there is an urgent need for NFA to assess whether the tuna longline fishing company is complying with the management plan and consider enforcement options. The best way to achieve this would be to increase observer coverage or investigate possibility of introducing some form of electronic monitoring (mounted cameras) of the catches.

7.5 Improved understanding of available data, harvests and trade

Key results

- NFA maintains data on the harvest, production and trade of shark and ray species and products derived from these species;
- PNG's longline fisheries reported average annual exports of shark fin of 189,000 kg (2004-2011) to the NFA, which compares to a much lower average export figure of 14,000 kg in Food and Agricultural Organisation (FAO) data for the same period suggesting that PNG's contribution to the international harvest of sharks and trade in shark fin has been severely underestimated in FAO data.

Discussion

On the first socio-economic field trip, available data on shark harvests and trade were investigated which provided an indication of the utilisation benefits of shark resources but was also used to inform the design of field work sampling regime for the broader project.

Relevant data was extracted by NFA staff from the database and provided to project staff (access to the database was not provided). Initially, data for 2004–2013 was provided for:

- Fishery catch and effort - for major fisheries (e.g. tuna longline, prawn trawl);
- Domestic shark fin purchases - provincial fin purchases reported by major fin buyers;
- Longline fishery exports - quantities and kina values for key products (e.g. fin, meat).

A draft report was developed to summarise available data and inform the project team about potential implications for the project (Appendix 21). In developing the report, data was verified using FAO trade data and Hong Kong import data (given that Hong Kong has historically been a shark fin trade hub). Since the report was drafted, preliminary 2014 data was provided but has not been incorporated. Data for additional years are likely to be available and were requested but were not forthcoming.

Domestic shark fin purchase data revealed that fin purchases were reported in a total of 14 provinces for 2004–2012. The average annual total reported purchases for the period was 13,253 kg. Reported purchases across PNG peaked at just under 26,000 kg in 2012, however, this may reflect double counting of fin that is shipped from provinces to Port Moresby (an issue which was confirmed through conversations with the main buyer in Port Moresby and which requires further investigation to resolve). High quantity provinces were identified as the National Capital District (NCD) (likely to reflect double counting), Milne Bay, Manus, New Ireland and Morobe. Despite issues with the veracity of the purchase data, its collection provides a cost-effective means to monitoring small-scale activities and could be used to inform NFA's management of this sector.

Shark longline and tuna longline companies reported an average annual export quantity for shark fin of 169,300 kg (2004–2012). This included a peak of 548,000 kg in 2011 (likely to be an overestimate). These quantities are far higher than quantities reported in both FAO and Hong Kong trade statistics. For example, PNG's longline companies reported average annual exports of shark fin of 189,000 kg (2004–2011) to the NFA, which compares to an average of 14,000 kg in FAO data for the same period. This may suggest that companies are exporting to somewhere other than Hong Kong (discussions with shark longliners indicated Taiwan as the main export destination). Reported export prices appeared to be significantly underreported in this dataset.

Shark Longline Fishery data shows that catch was dominated by blue shark between 2002 and 2005 but became dominated by silky shark catch post 2006, which peaked in 2011 at 1.23 million kg, nearly 90% of total catch. From 2011, reported catches declined significantly to 0.71 million kg in 2013. The fishery ceased operating with a ban on silky shark retention in 2014.

7.6 Socio-economic status and characteristics for case study sites

Key results

- The Louisiade case study demonstrated that isolate island communities with limited resources and infrastructure may exhibit high dependence on shark fin due to the ease with which it can be accessed, processed, stored and transported;
- Market chains for shark fin were revealed to be highly dependent on those of sea cucumber, with reduced buying of fin following the sea cucumber ban;
- While falling prices and market access were contributing to reduced harvesting, the reopening of the sea cucumber fishery will likely reopen market chains for fin, increase harvesting and will require increased management of shark resources.

Discussion

A case study approach was used to assess the socio-economic status of PNG's shark resources. NFA domestic shark fin data were used to select case-study sites. Data collection focused on fishers, buyers and community members to address two questions:

- How dependent are local communities on shark resources?
- Given socio-economic status, what management approaches might be appropriate?

The first field trip focused on small-scale activities in the Louisiade Archipelago, Milne Bay province. Field observations revealed that communities were communalistic and engaged in subsistence and trading activities (with the cash economy being relatively new). Cash income sources were few and largely marine focused. Shark was consistently cited as the most important income source followed by trochus and fresh fish. However, sea cucumber was noted as the major income source prior to the 2009 sea cucumber harvesting ban.

Data analysis confirmed a large reduction in income following the sea cucumber closure, which was contrary to expectations. Modelling showed that following the sea cucumber ban, quarterly shark fin production was on average 68 kg lower (holding all else constant) and associated income fell by 75%. Driving these changes were falling prices for fin, a decline in market access (due to the sea cucumber ban), geographical isolation, high fuel costs and low returns to shark fin (relative to sea cucumber).

Market access could improve if the sea cucumber fishery is reopened and/or shark fin prices increase. Therefore, low-cost, community-based management of shark resources based on the allocation of allowable shark catches to ward communities was noted as a potential management option. Such an approach would take advantage of the communal characteristics of local communities as well as the fishery data collection and monitoring mechanisms that are currently used by local governments.

The second socio-economic field trip focused on two areas - New Ireland and Manus provinces. In general, a decline in shark fishing and fin production was noted by all stakeholders due to a fall in prices and a lack of buyers and/or market access. A similar socioeconomic context to that observed in Milne Bay was observed in both provinces, although greater levels of trading and income earning activities were observed reflecting closer proximity to population and markets.

Socio-economic dependence on shark was relatively low, particularly in terms of income, for areas visited. However, Nigoherm LLG in Manus province (which was not visited) provided an example of one location with similar characteristics to the Louisiades (high fin production, isolation from markets, limited land etc.) where socio-economic dependence may be relatively higher. Shark and ray consumption was observed to be more common relative to the Louisiades. Examples of cultural and spiritual values attached to shark were also found: in New Ireland with traditional shark calling practices and in Manus with shark and stingray often a part of island culture *tambus* (taboos). Additional information can be found in Appendix 20.

7.7 Life history parameters for key shark species

Key results

- Key shark species in the shark longline fishery determined;
- Life history parameters determined for the silky shark, grey reef shark, silvertip shark, oceanic whitetip and blue shark;
- Life history parameters currently being determined for the scalloped hammerhead, and bigeye and pelagic threshers.

Discussion

The key shark species in the shark longline fishery were determined at the start of the project, prior to observers heading to sea. These were largely predetermined from data available in previous NFA reports on this fishery, in particular Kumoru (2003b). The results from the first observer trips confirm the key shark species as: silky shark *C. falciformis*, grey reef shark *C. amblyrhynchos*, scalloped hammerhead *S. lewini*, silvertip shark *C. albimarginatus*, oceanic whitetip *C. longimanus*, blue shark *Prionace glauca*, and common blacktip *C. limbatus*.

Initial focus was placed on obtaining detailed life history data for the grey reef and silvertip sharks. Although less abundant than some other key species, no detailed regional age and growth parameters existed for these species and were thus considered more important to address first. Since a large amount of vertebrae was collected early in the project, it allowed for subsequent age and growth studies on the silky shark, oceanic whitetip and blue shark to be undertaken.

Grey reef sharks were found to mature at ~134 cm total length (TL) and ~9 years of age in females and ~123 cm TL and ~6 years in males, with maximum ages of 15 and 13 years for females and males, respectively. PNG populations appear to grow slightly faster than northern Australian populations. For more information see Appendix 10. Silvertip sharks were found to mature at ~209 cm total length (TL) and ~15 years of age in females and ~175 cm TL and ~10.5 years in males, with maximum ages of 18 years for both sexes. This study provides the first age and growth data for this species. For more information see Appendix 11. Oceanic whitetip sharks were found to mature at ~224 cm total length (TL) and ~16 years of age in females and ~193 cm TL and ~10 years in males, with maximum ages of 17 and 18 years for females and males, respectively. PNG populations have considerably slower growth than populations from the North Pacific and south-west Atlantic oceans, highlighting need for using local population assessments. For more information see Appendix 12.

Silky sharks were found to mature at ~204 cm total length (TL) and ~14 years of age in females and ~183 cm TL and ~12 years in males, with maximum ages of 28 and 23 years for females and males, respectively. Females have an average litter size of 8 (3–13) pups. The life history parameters of the PNG population suggest a significant risk from fisheries exploitation without careful population management. For more information see Appendix 13. Blue sharks were found to attain maximum ages of 25 and 22 years for females and males, respectively, but are likely underestimates. Although a global species, it was found that blue sharks show variation in growth between regions. For more information see Appendix 44.

Age and growth studies on the scalloped hammerhead, bigeye thresher and pelagic thresher are currently being undertaken. The life history parameters produced for the key shark species during this project provide crucial parameters for demographic modelling of local populations in PNG waters which were not possible prior to this project. Using life history parameters from other regions to assess local populations can result in inaccurate estimates and should be avoided.

7.8 Shark and ray bycatch in the Gulf of Papua prawn trawl fishery

Key results

- 42 species of sharks and rays were recorded from the GoP prawn trawl fishery;
- >1200 hours of trawling was investigated through the observer program allowing for estimates of annual catches of sharks and rays to be determine for this fishery;
- Size composition data from abundant species reveals significant catches of immature individuals.

Discussion

The 7 observer trips undertaken during the observer program for this fishery resulted in a total of 403 observed trawl sets representing 1273 hours of trawling activity. Sharks and rays were recorded from 339 of the trawl sets observed, with a catch-per-unit effort (CPUE) of 1.6 sharks or rays caught per hour of trawling, with a slightly higher CPUE recorded in the western half of the Gulf of Papua than in the eastern half.

A total of 40 species of sharks and rays from 14 families were recorded by the observer program, with an additional family and two species recorded based on images supplied by NFA from previous observer trips. The lengths (sharks and shark-like rays) or width (other rays) were recorded for all individuals. Weights were only taken when possible and when no weight was recorded, an estimated weight was calculated using species-specific length vs. weight equations taken from the literature or from data collected on this project. Using this data, a total biomass of ~4.3 tonnes of sharks and rays was estimated from the 2030 individual sharks and rays.

The most abundant species in the bycatch was the Australian sharpnose shark *Rhizoprionodon taylori* (~29% of catch), followed by the whitecheek shark *Carcharhinus coatesi* (9.5%) and Australian butterfly ray *Gymnura australis* (~8%). The species which contributed the most to the total biomass were the eyebrow wedgefish *Rhynchobatus palpebratus* (~9%), the Australian whipray *Himantura australis* (~9%) and *R. taylori* (~8%).

The shark and ray bycatch of the prawn trawl fishery was dominated by immature individuals of most species. The catch of some species consisted of only immature individuals, e.g. scalloped hammerhead *Sphyrna lewini*, spinner shark *Carcharhinus brevipinna*, common blacktip *Carcharhinus limbatus*, and the Merauke stingray *Hemitrygon longicauda*. Only some of the smaller species were represented in the catch by all life stages, e.g. *R. taylori*, *C. coatesi*, creek whaler *Carcharhinus fitzroyensis*, *G. australis*, plain maskray *Neotrygon annotata*, and bluebanded eagle ray *Aetomylaeus caeruleofasciatus*.

The prawn trawl vessels do not deploy bycatch reduction (BRD) or turtle excluder devices (TED) resulting in a high elasmobranch bycatch. Investigation of the viability of introducing BRDs and TEDs into the Gulf of Papua prawn trawl fishery is currently being investigated on a separate CSIRO and NFA led project; thus, was not explored in this project.

Given the large number of trawling hours observed on this project, it is possible to use this data to produce rough estimates of the total annual catches of sharks and rays. Available annual trawling hour data provided in Liviko (2012) is clearly erroneous and accurate data is currently being sourced from NFA records in order to generate annual estimate catches.

At the project development stage, the prawn trawl bycatch of sharks and rays was considered to be negligible by NFA with no animals retained. The observer program employed was greater than planned due to the foresight of Leontine Baje at NFA who increased the coverage which resulted in the robust data now available. It also showed that all sharks and rays caught are finned or dead or moribund at capture.

See Appendix 16 for figures and tables relating to the currently in preparation paper.

7.9 Life history of sharks and rays in the Gulf of Papua

Key results

- Life history parameters determine for the two key shark species, i.e. Australian Sharpnose shark and whitecheek shark;
- Size at maturity and basic reproductive parameters determined for abundant species;
- The first PhD undertaken by an NFA staff member.

Discussion

Obtaining biological data from the key shark and ray species caught by prawn trawlers in the Gulf of Papua was not originally planned for this project. This was due to the planned low observer coverage in this fishery. The fortuitous increased level of observer coverage allowed for the collection of a large amount of data and samples for sharks and rays taken in this fishery.

In September 2014, Leontine Baje (NFA) was awarded a John Allwright Fellowship to undertake a Masters project at JCU in Townsville (commenced mid-2015). The initial concept was to use the trawl data and samples to undertake:

- Life history work on the Australian Sharpnose Shark; and
- Dietary partitioning in the key shark species.

This study was upgraded to a PhD candidature in 2017 with two further components added (due for completion in mid-2018):

- Life history work on the whitecheek shark; and
- Ecological Risk Assessment for sharks and rays in the Gulf of Papua.

The age and growth research on the Australian Sharpnose shark *Rhizoprionodon taylori* found that females mature at ~47 cm TL and ~0.9 years and males at 42 cm TL and 0.5 years and reach a maximum age of 4.6 and 3.6 years, respectively. The results from this study infer that, due to its high productivity and fast growth rate, this species is possibly able to withstand current fishing pressure. See Appendix 14 for more information.

The age and growth research on the whitecheek shark *Carcharhinus coatesi* found that females mature at ~71 cm TL and males at ~66 cm TL and both sexes mature at ~5 years of age and reach a maximum age of 10.5 years (Baje et al., in prep). This species was found to grow faster in the Gulf of Papua compared to northern Australian populations. See Appendix 15 for more information.

Size at maturity (S_{50}) was also calculated for the following trawl caught species: the milk shark *Rhizoprionodon acutus* (males at 59 cm TL), the Australian butterfly ray *Gymnura australis* (females at 50 cm DW, males at 34 cm DW), the blackspotted whipray *Maculabatis astra* (males at ~41 cm DW), and the blue-banded Eagle Ray (males at 36 cm DW).

The most important aspect of this component is the capacity building of an NFA staff member through the JAF scholarship. Leontine Baje is currently due to submit her PhD in mid-2018 and will become the first NFA staff member to be awarded a PhD. Leontine's PhD will be awarded through James Cook University.

7.10 Assessing shark catches in coastal fisheries

Key results

- Catches of sharks were relatively low in the coastal fisheries of a number of locations, but high in some areas, e.g. East Sepik and Milne Bay provinces;
- Examination of dried shark fins was imperative for obtaining surrogate catch data and provided the best insights into the shark catches in the coastal fisheries.

Discussion

During the first field trip to Daru in October 2014, it became evident early in the trip that we were unlikely to encounter large numbers of whole sharks and rays during the survey period. In order to obtain important catch composition and diversity information, examination of dried shark fin was quickly determined to be critical for this component. For example, during the week-long survey of Daru, 18 sharks and rays were recorded representing 11 species. Examination of dried fins yielded 66 individual sharks and rays representing 15 species, with only 2 of these species overlapping with the 11 whole individuals recorded.

The fin sampling methodology developed involved isolating first dorsal fins from the whole fin batch to determine how many individuals were present; photograph each dorsal fin; take 3 standard measurements where possible (height, length, anterior margin length); take a small fin clip for genetic analyses. The genetic sample was barcoded to determine species identity (see 7.15 below). Once species was known, the fin measurements could be used to determine length of the individual and from that an estimated weight can be determined. Thus, from a batch of >200 dried fins, the total number of individuals represented was determined, their sizes and the total biomass of that catch. Although the time period the fins represent and effort data was not available, species and catch composition could be accurately determined.

To further test the fin sampling methodology developed, focus was placed on sampling a large batch of fins to obtain a more robust dataset. The Milne Bay survey trip in March 2016 provided that opportunity with a 150 kg batch of fins examined at one of the fin buyers. A total of 623 individual sharks and rays were found in this batch, representing 22 species and equating to a total biomass of 9.1 tonnes. The most abundant species in the catch was grey reef sharks (~40%) followed by blacktip reef sharks (11%) and silky sharks (9%). It is important to note that the two most abundant species are also key species from the target longline fishery which highlights the strong overlap in catch composition between the various fisheries. This larger sample size provided a comprehensive data set to enable scaling up to estimate the approximate total annual catch for the Milne Bay region. This yielded annual catch estimates of between 127 and 229 tonnes of sharks and rays caught by coastal fishers in the Milne Bay province between 2010 and 2013. For more information see Appendix 19.

The fin sampling methodology was also employed in the survey trips to Buka in Bougainville (63 fins sampled; grey reef, silvertip and silky sharks dominated), Kavieng in New Ireland (21 fins sampled; grey reef and silky sharks dominated), and Wewak (69 fins sampled; winghead shark dominated).

No whole specimens were observed during the survey trips to Kavieng and Buka, but a coastal gillnet fishery at the mouth of the Sepik River was observed and a large number of whole specimens observed. A total of 110 sharks and rays were recorded in this fishery over 7 days, with the most dominant species being the bull shark (21%), graceful shark (19%), winghead shark (19%) and hardnose shark (13%).

Thus, multiple survey techniques were required to thoroughly investigate the coastal fisheries catches. More detailed investigation of these coastal fisheries is required.

7.11 Demographic modelling of key shark species

Key results

- Demographic models produced for 2 key species to date;
- Demographic models being developed for a further 6 species;
- A new demographic modelling method developed.

Discussion

The stock assessment component was originally to be led by CSIRO in this project but staff changes at CSIRO in the second year led to a replanning of this component. Prior to leaving CSIRO, one of the stock assessment staff, Rik Buckworth, worked with Jonathan Smart, during his PhD candidature through JCU, regarding increasing his involvement in this component as part of his PhD studies. Following this, JCU led this component of the project in the last 2 years.

Stochastic demographic analyses were first conducted on the silvertip shark (Appendix 31) using the life history parameters determined in this project for PNG populations. The results of this study suggest that populations will decline when fishing mortality was applied to all age classes. A gauntlet fishery (harvesting only <1 m TL juveniles) could possibly result in maintaining populations, but would require protection of larger individuals. It was noted though that protecting other age-classes would be difficult.

An analysis of intraspecific variation in demographic attributes for the pan-tropically distributed silky shark is currently being finalised and due for journal submission soon. Demographic analyses are also currently underway for another 6 pelagic shark species, scalloped hammerhead, silky shark, blue shark, oceanic whitetip, pelagic thresher and bigeye thresher, using life history parameters generated in this project. These will be published a single, multispecies paper in the coming months.

7.12 Estimation of annual landings of sharks and rays in PNG

Key results

- An estimate of 5,470 tonnes of sharks and rays caught in PNG in 2011 was calculated based on synthesis of data available for each of the fisheries capturing sharks and rays together with project data;
- Average annual catches of sharks and rays of ~4,100 tonnes in PNG;
- Improved data management and access is required to produce more accurate estimates.

Discussion

There are currently no total annual catch estimates for sharks and rays in PNG. Various sources of data are required in order to estimate annual landings, e.g. observer data from the purse seine and longline fisheries and project data for coastal and trawl fisheries. Validation of data provided by NFA was difficult and further work is required to validate some of the datasets, particularly effort data. Access to historical data from NFA proved difficult during the project so most data used was obtained from the various country reports.

Tuna longline shark bycatch estimates – data on number of vessels, effort (number of hooks), and tonnage of sharks was available for the period 2006-2015. The CPUE (sharks per ‘000 hooks) from the project observer data was found to be significantly lower than those reported in the NFA data. The number of hooks deployed in this fishery appears to be very high and not reflective of what the project was observing. Without access to more detailed data, we could not resolve this. Also, there is some concern that the number of hooks observed in the project data may be too low resulting in inflated CPUE estimates. Due to the unresolved issues with this data, the average annual estimate of shark catches from this fishery in the 2011-2015 period reported in NFA (2016) of 110 tonnes was used. We consider this a conservative estimate and catches are possibly much higher. It should be noted that the NFA shark fin export data for the shark and tuna longline fisheries was not used to calculate these figures. These values was not used in these calculations due to uncertainty in how they were produced.

Shark longline fishery catch estimates – effort data available for 2007 to 2014 are considered to be accurate. Annual catch estimates provided in the country reports are based on low observer coverage. As a result, CPUE estimates and average weight of individual sharks caught obtained from the project’s observer data were used to calculate estimated annual landings for this period. The resulting average annual estimate for 2007-2013 was 2,537 tonnes of sharks, with 781 tonnes in the first half of 2014 prior to the fisheries closure in July 2014.

Purse-seine fishery shark and ray bycatch estimates – observer coverage is excellent in this fishery and thus good data is available. Detailed catch and effort data was taken from Nicol *et al.* (2006). This data provided total annual shark and ray catches between 1995 and 2006. Country reports provided total catch data for the purse seine fleet (domestic and foreign within PNG waters) for 2002 to 2015. These data sources were combined to estimate annual total shark and ray landings for 2007 to 2014 (2015 assumed incomplete data). This enabled an average annual catch estimate for sharks and rays of 877 tonnes for the period 2006-2014.

Prawn trawl fishery bycatch estimates – the detailed project observer data for this fishery allowed for the calculation of an accurate CPUE (tonnes/’000 hrs trawling) of sharks and rays in this fishery. This estimate could then be used to generate annual estimates using reported total annual effort (number of trawling hours). However, the effort data reported for this fishery in Liviko (2012) for 1990-2011 appears to be erroneous with more hours of trawling per vessel than actual number of hours in the year. This data issue could not be resolved so to obtain surrogate information, effort was calculated based on information in Liviko (2012) stating that each vessel trawls for an average of 250 days per year with an average of 19 hrs of trawling per fishing day combined with the known number of vessels operating in that year. This yielded far lower and more realistic effort estimates and allowed for estimation of annual landings of sharks and rays, i.e. average annual catches of 140 tonnes of sharks and rays in the 2006-2011 period.

Coastal fisheries catch estimates – there is very little available data for the shark and ray catches in the coastal fisheries in PNG. To obtain some catch estimates, detailed shark fin quantities for each province in the 2010-2013 period were obtained from NFA data. The project data obtained from the large batch of shark fins examined in Milne Bay Province (see 7.10) enabled estimation of total annual whole shark landings for PNG. These estimates should be treated with caution as they are based on a number of assumptions, foremost the assumption that the data is accurate for all provinces. For example, in the New Ireland Province, the 2012 data is far higher than in other years. Following our survey of that province and interviews with stakeholders, we are confident this is erroneous and possibly the result of incorrect scaling (if divided by 12 [months] the resulting figure is close to amounts in other years. Double counting is also an issue and to overcome this we assumed the National Capital District data was already counted in other provincial datasets and was excluded from calculations. Average annual estimates of sharks and ray catches for the 2010-2013 period were 440 tonnes. This is likely to be an underestimate as it assumes the catches all ended up producing dried fins, i.e. excluding rays without fins (stingrays etc) and sharks with no fin value (nurse sharks, zebra sharks).

Based on the average catch estimates in each of the fisheries above, the estimated total average annual catches of sharks and rays in PNG is ~4,100 tonnes. For the one year, 2011, where annual data was calculated in all 5 fisheries, the estimated shark and ray catches were 5,470 tonnes. Following the closure of the shark longline fishery in PNG, average annual catches theoretically have fallen to ~1,600 tonnes. These figures should be treated with caution but they are the best available estimates of shark and ray landings in PNG.

7.13 Identification of multiple paternity for two key species

Key results

- Multiple paternity identified for grey reef and scalloped hammerhead sharks

Discussion

During longline sampling, observers collected fin clips from pregnant sharks in addition to taking samples from each of their unborn pups. This rigorous sample collection enabled the project to test for multiple paternity for two species - the grey reef shark (*Carcharhinus amblyrhynchos*) and scalloped hammerhead shark (*Sphyrna lewini*).

Multiple paternity describes when a female mates with many males during a single breeding event. This leads to individual pups within the litters being sired by multiple fathers. Detecting and understanding the occurrence and prevalence of multiple paternity in populations can aid in understanding breeding behaviours and the genetic health of a population.

Multiple paternity was identified for both grey reef and scalloped hammerhead sharks. For more information see Appendix 29.

7.14 Population genetic assessment of key species

Key results

- More than 900 genetic samples were collected from three key species; silvertip, grey reef and scalloped hammerhead sharks
- Genetic assessment for all three species nearing completion; novel genomic resources developed for each species
- Preliminary results suggest Papua New Guinea shares stocks with Australia and Indonesia for all three species

Discussion

Three species commonly captured in longline and coastal fisheries were selected for genetic analyses. These species were the silvertip shark (*Carcharhinus albimarginatus*), the grey reef shark (*Carcharhinus amblyrhynchos*) and the scalloped hammerhead (*Sphyrna lewini*).

Three types of genetic markers were used for analyses - mtDNA, microsatellites and SNPs. The primary aim for utilising these three marker types was to increase the resolution and analytical power for resolving population structure and therefore delineating stock boundaries within each shark species.

Throughout the study, a number of novel genetic markers were developed specifically for each species thereby enabling capacity for future studies of the three shark species. For example, three next generation SNP establishment libraries were developed (one for each species) and a suite of microsatellite markers were characterised and can now be used for global silvertip analyses

Samples from outside of the central Indo-Pacific (PNG, Indonesia and Australia) were sourced in order to understand where breaks in gene flow/limited dispersal might be occurring. For silvertip and grey reef sharks, samples from the Seychelles were added to analyses, while scalloped hammerhead analyses included samples from Fiji, Hawaii, Gulf of California, Gulf of Mexico and the Seychelles.

Silvertip shark and grey reef shark:-

- Genetic analyses have revealed gene flow exists between individuals from PNG, Indonesia and Australia; while no gene flow is apparent between the central Indo-Pacific and the Seychelles
- Therefore, dispersal is possible throughout the central Indo-Pacific, However the level of migration (and its demographic significance) between regions is still to be estimated. Limited movements are occurring across the Indian Ocean westward

Scalloped hammerhead shark:-

- Preliminary results suggest high levels of gene flow are apparent between central Indo-Pacific locations

The findings from the population genetic analyses for each species are currently being collated into three journal publications to be submitted early-mid 2018. Figures relating to the results for each of the three species are provided in Appendix 30.

7.15 Developing management options for PNGs National Fisheries Authority

Key results

- A total of 11 management actions for NFA to consider were developed with the aim of ensuring sustainable use of sharks and rays into the future;
- A Policy Brief was developed which summarises each management option and the justification and urgency also provided.

Discussion

The original plan for the project was to hold the final stock assessment workshop in Port Moresby and to discuss management options for sharks and rays in PNG. This would enable NFA staff involved not only in fisheries management but also policy decisions and enforcement to be involved in the process. Unfortunately, due largely to unforeseen staffing shortages at NFA, the final workshop could not be held in Port Moresby but instead at CSIRO in Hobart in January 2018. Only a single NFA staff member was available for the workshop, but a representative for all components of the project was in attendance. As a result, emphasis was placed on developing well justified, evidence-based management options for fisheries catching sharks and rays in PNG and developing a Policy Brief (Appendix 32) which NFA can use now and in the future.

The management options developed are:

- Meeting international obligations – e.g. dealing with CITES compliance issues;
- Improving understanding of coastal fisheries – use of sharks and rays essential for livelihoods of some communities, e.g. in Milne Bay Province;
- Maintaining national fisheries observer programs – important for obtaining accurate fishery data;
- Enforcement of current management measures – e.g. retention of shark fins in tuna longline fishery despite license not allowing finning;
- Improving data collection and management systems – fundamental requirement;
- Improving understanding of market chains for shark and ray and related commodities – understand drivers of shark and ray harvesting and improve catch monitoring;
- Monitoring of new or trial fisheries – assess their potential or actual impact on sustainable management;
- Develop a National Plan of Action for sharks – develop a more holistic view of shark management in PNG;
- Safe handling and release guides – demonstrate sustainable practices for CITES;
- Use of project data to improve shark management – the large database developed in the current project should be used as a baseline moving forward;
- Community stewardship – lead to more effective small-scale management.

See Appendix 32 for more information on the management options proposed.

7.16 DNA barcoding as a species identification tool

Key results

- A total of 398 ND2 sequences generated by the College of Charleston;
- Approximately 1,200 samples were COI sequenced and 55 ND2 sequences generated by CSIRO;
- DNA barcoding enabled verified species identifications from a range of shark and ray tissue (i.e. vertebrae, muscle, fin) when species could not be morphologically confirmed;
- DNA barcode sequence data used in a number of taxonomic species papers
- A PNG specific sequence library established on the international Barcode of Life Database (BOLD).

Discussion

A collaborative project between CSIRO and the College of Charleston – the Chondrichthyan Tree of Life (CTOL) project – funded by the National Science Foundation (NSF) was able to sequence a number of genetic samples collected in the early stages of this project. This value added to the CTOL project by incorporating a large number of samples from a region they had poor representation and in turn our project was able to obtain 398 ND2 sequences without cost other than freight to the US. Since the CTOL project required samples from retained and/or photographed whole specimens, only samples from several components of this project could be sent. These included samples from the trawl fishery, deepwater samples donated by Taiwan collections, and some from the coastal fisheries surveys. Of the 398 sequences obtained, 43 were misidentified. ND2 sequences and resulting trees were used in a number of taxonomic papers (Appendices 22-26, 36-38).

The large number of samples from the longline observers and the coastal fisheries surveys (mostly from dried fins, see Appleyard *et al.* 2018) were analysed at CSIRO marine laboratories on the 3130XL DNA Autoanalyser, primarily for the COI gene sequence, as well as a limited number of samples that were ND2 sequenced, for some samples (e.g., Australian blacktip shark *C. tilstoni*) that required additional verification. The DNA barcoding enabled species verification in more than 95% of cases; thus DNA barcoding provided the important validated species data required for investigation of the coastal and longline fisheries and for studies where species identifications were paramount (i.e., new species records and revisions, population genetics and age/growth demography).

The COI sequences generated during this project by CSIRO have been uploaded to BOLD into a PNG specific project (‘SOPNG – Sharks and rays of PNG’, http://www.barcodinglife.com/) which will house the mtDNA sequencing and associated metadata. In addition, representative COI sequences from species identified based on samples from this project have been deposited in GenBank (www.ncbi.nlm.nih.gov/genbank) particularly where the samples were part of published manuscripts (e.g. Appendix 19).

An initial aim of the project was to select a PNG scientist to become an active participant in the BOLD project. However, a person was not selected for this but this should be sought in the future to ensure continued involvement in this international initiative.

7.17 Exploring the deep-water shark and ray fauna of PNG

Key results

- Opportunistic data sources and sampling resulted in an additional 25 species and 10 families of deep-water sharks and rays being discovered from PNG waters.

Discussion

Prior to this project, the deep-water shark and ray fauna was largely unknown. Several opportunistic data sources provided useful insights into the deep-water fauna. First, and most importantly, Dr Ralph Mana at UPNG alerted us to the deep-water surveys that had been undertaken throughout PNG between 2010 and 2014 on-board the French research vessel *Alis*. We were informed that sharks and rays had been caught and that all fish collections had been deposited in either the National Taiwan University Museum (NTUM) or Academia Sinica in Taipei, Taiwan. The project leader was able to visit these collections in January 2016 and subsequently borrow a number of important specimens for more detailed analyses. Examination of the deep-water PNG specimens in the Taiwan collections resulted in description of 5 new shark and ray species from PNG (Appendices 22-26) and a further 18 species not previously recorded from PNG.

Contact was also made during the project with a consultant doing some small-scale, deep-water fishing in the Huon Gulf. This resulted in several further shark records including a species of gulper shark, previously only known from Taiwan and Indonesia, whose identity was uncertain. Investigation of this species found it was a new species which was named and described (see Appendix 40).

During the coastal fisheries survey to Kavieng, deep water longline gear was loaned to the Fisheries College (via Jeff Kinch) for opportunistic use during fishing trips if possible. Jeff allowed us to use their research vessel *Pokajam* to do a 24hr period of deep-water longlining to trial the gear. This resulted in about 10 sharks from 3 species being caught, one of which was a new record for PNG.

Thus, the opportunistic data obtained on deep water sharks during this project increased the number of true deep-water species known in PNG from 7 species from 6 families, to 32 species from 16 families. These results played an important role in documenting the biodiversity of sharks and rays in PNG.

7.18 Documenting the biodiversity of sharks and rays in PNG

Key results

- A checklist of all 132 species of sharks and rays confirmed from PNG waters was produced;
- A field guide to all 132 species of sharks and rays in PNG was published.

Discussion

Biological collections (e.g. natural history museums) are a treasure trove of verifiable data and specimens. CSIRO was collaborating on a concurrently running NSF project on developing a Chondrichthyan (shark and ray) Tree of Life project in the first two years of this project. The NSF project funded multiple trips to natural history museums around the world and during these trips, all specimens collected from PNG waters were documented and re-identified. This was a particularly useful exercise as it validated many of the early literature records by matching up the specimen collectors with expeditions. This project collaboration enabled all PNG specimens deposited in the major biological collections in the world to be documented as well as confirming biodiversity records for PNG.

Verified species records were also generated through the various components of this project as well as from opportunistic data sources (see 7.15). An identification confidence level was assigned to each specimen record based on a system used by the Australian National Fish Collection at CSIRO: 1 – verified by an expert on group; 2 – verified, but not an expert on that group; 3 – probably correct id but some doubt; 4 – serious doubt over id and requires more attention.

The resulting shark and ray biodiversity data was compiled and published in two separate mediums. Firstly, an annotated checklist was developed (Appendix 36) which, for each species of sharks and rays, includes a list of synonyms (other names) used for that species in PNG waters, a list of verified specimens of that species from PNG, and any other relevant information (e.g. first record for PNG, etc). This checklist will provide an important scientific baseline for the biodiversity of sharks and rays in PNG which was previously unavailable.

Secondly, the biodiversity information was used as the backbone for a field guide to the sharks and rays of PNG (Appendix 42). This guide contains a two-page spread for each of the 132 species (including images and information on key characteristics, size, distribution, colour, habitat and biology and conservation status), a key to the families and genera, a key to dried shark fins, and a checklist of all species. The primary aim of this guide is to improve species identification in PNG and is aimed primarily at observers, fisheries officers, and other data collectors. Its layout was designed also to appeal to a general audience, such as divers and general enthusiasts. The key to the dried fins is the first such key generated for the region.

7.19 Expanding and upgrading of the PNG national fish collection

Key results

- A total of 322 shark and ray specimens were retained during the project, of these 122 were deposited in the Australian National Fish Collection in CSIRO and 200 in the National Fish Collection housed at UPNG;
- Substantial upgrading of the existing collection was carried out.

Discussion

During early visits to the fish collection at UPNG, it was apparent that many specimens were in poor condition and required urgent maintenance. The lack of power and running water combined with the build-up of many years of dirt and mould made this a challenging component of the project.

Firstly, all shark and ray specimens present in the collection were documented and re-identified. They were then upgraded to new containers (particularly for specimens in 30L drums) or fluids replaced with clean ethanol. An empty glass aquarium contained a total of 93 shark jaws and 12 sawfish rostra (saws) with most jaws covered in mould and insect larvae. These were all cleaned, photographed and re-identified, relabelled and placed onto shelves in a compactus. They represent an important component of this collection.

Various shark and ray specimens were retained for the collection throughout the project, mainly from the prawn trawl bycatch, but also from the coastal fisheries surveys and opportunistic sources. Additional larger containers were brought into the collection to allow for fixation of specimens in their natural state and not bent into smaller containers. The largest was a ~500L plastic tank and trolley which can hold sharks up to 1.8 m in length with ease. A total of 322 specimens were retained. Specimens were deposited in the UPNG collection and in the ANFC to allow for duplication of this important collection.

The poor condition of some parts of the collection prompted us to allocate some time and resources into upgrading these parts. This was mostly undertaken during a workshop in late August 2016 led by CSIRO. Most notably, all plastic 30L drums (~20) were replaced (most had already split and specimens inside damaged) and specimens reorganised into family groupings to allow for easier searching. In addition, ~500 new jars with plastic inserts (to reduce evaporation) were brought into the collection and used to replace damaged jars. More than 800L of clean ethanol was used during the overall upgrade of the collection.

While the whole collection could not be upgraded during this project, it represented the first major effort to improve the collection since its deposition at UPNG in 2000 (which was funded by ACIAR and NFA). The majority of specimens in the collection were collected in the 1970s and 1980s but a substantial portion was lost after the Kanudi Fisheries Research Station, where it was originally housed, relocated into Port Moresby city centre. Although staff moved, the collection was left without protection. It is estimated that ~80% of the sharks and rays were lost during this time, prior to its move to UPNG.

This project resulted in a substantial upgrade to the national fish collection at UPNG, not only through the actions mentioned above. Following our site visit to the fish collection during the final project review in June 2017, Dr Mana was able to secure K5000 from NFA to thoroughly clean the collection (see Appendix 35). More than 30 people were involved in this clean up. Despite the great progress in upgrading the collection, there are two key issues which need addressing in the future:

1. The collection needs a curator in charge of maintaining the collection;
2. The building is falling apart and the collection needs to be moved to a new building with serviced infrastructure (i.e. running water, electricity).

8 Impacts

8.1 Scientific impacts – now and in 5 years

8.1.1 Socio-economics

The detailed socio-economic case study conducted in Milne Bay (Vieira *et al*., 2016) provides detailed information on the difficult trade-offs required for policy makers between conservation and community welfare. The findings from this case study are relevant to other areas of PNG with similar characteristics and will be particularly useful when developing management guidelines for the coastal artisanal fisheries over the next 5 years or more, for which there is limited data currently available.

The data highlighting the discrepancy between NFA export data and data reported to FAO was an important finding that will need to be addressed by NFA in the future. Similarly, simple data entry errors that lead to large data inaccuracies (e.g. double counting of shark fin when it is traded between domestic buyers more than once) were also observed. There is an increasing demand for accurate reporting of fisheries data and this finding provides NFA with the necessary information to address this issue in the future.

8.1.2 Catch composition and life history data

The accurate catch composition data collected during this study for the various fisheries represents an important baseline of information for future studies. All samples and data collected can be traced back to a single fishing event from an observer or survey trip, thus all data is traceable and verifiable. This will be important for NFA in the future as it represents an accurate dataset from which changes from baseline biodiversity levels can be monitored which was not available previously. Understanding of trends in fisheries is crucial for attaining sustainable fishing practices and this data is an important output of the project.

The life history parameters collected for the key species of sharks from the longline and prawn trawl fisheries fed directly into the stock assessment component of the project. The resulting demographic analyses using these regionally appropriate life history parameters are far more robust and accurate than if parameters from other regions were used. This is emphasised by some of the analyses highlighting regional differences in life history parameters. Thus, use of parameters from other regions would have produced inaccurate assessments of population status. The life history parameters collected in this study have been published in international journals and represent an important series of biological studies on PNG fishes. Prior to this study, the only detailed life history information published for a fish species in PNG was for the barramundi. They thus represent a significant increase in scientific knowledge on PNG fishes which can be used as a model for future studies in PNG.

8.1.3 Genetics

The DNA barcoding work undertaken in this project is extremely important as it can be linked, in most cases, to specimens or images and is now housed on an international database. These data are crucial for understanding regional biodiversity as poorly studied regions such as PNG often lie in important biogeographical areas where biodiversity can be influenced from multiple regions, and as such can be difficult to make assumptions about.

The population genetic components provide a better understanding of the connectivity between populations of 3 of the key shark species across the region. For example, grey reef sharks and silvertip sharks have shared stocks with Australia. This information is crucial for both PNG and Australian fisheries managers (i.e. cross jurisdictional management) and will need to be considered in all future management plans for these species.

8.1.4 Improved biodiversity information

Taxonomic research during the project has dramatically improved our understanding of the shark and ray biodiversity of PNG with more than 30 species previously not known from PNG and about 10 species new to science. The comprehensive checklist published during this project (White & Ko'ou, 2018) provides the first detailed account of all the shark and ray species found in PNG waters. This will be an important resource for all marine biodiversity studies and any future marine bioregional studies in PNG or the region. The field guide produced at the end of the project (White *et al*., 2018) provides an extremely important resource for PNG to assist with improving data quality through improved species identification and biological information. This guide will have a longitudinal impact in PNG as it represents the first detailed guide to the sharks and rays in PNG since the 1960s.

The project drastically improved our knowledge of the deepwater shark and ray fauna of PNG with 6 new species discovered and named and a further 18 species not previously recorded from PNG. Prior to the project only a handful of deepwater species were confirmed from PNG. Information on the deepwater species in PNG is of increasing importance due to the growth in deep sea mining activities and mining tailings in deepwater areas. Sharks and rays are important indicator species so any ecological risk assessments of deep water regions in PNG will be greatly improved by having a detailed and accurate knowledge of the sharks and rays present.

8.1.5 Conservation and threatened species

Research on several threatened species in PNG waters during this project has yielded extremely important information for the broader scientific community as well as for PNG's conservation departments. A thorough investigation into historical and contemporary catches of sawfish in PNG (White *et al*., 2017a) provided the first such data on sawfish for PNG. The global conservation strategy for sawfishes includes obtaining information from countries with no available data, with PNG being one of the most important of those due to its proximity to northern Australia, a stronghold for sawfish. Despite sawfish being extinct from more than 25 countries, they are in relatively high numbers in PNG. This is critical information for conservation and fisheries managers in PNG and future management needs to address this issue as they are listed on Appendix I of CITES to which PNG is a party to. Furthermore, our research recorded several specimens of the dwarf sawfish which had been considered possibly extinct in PNG waters. This data is crucial for updating future conservation assessments.

Our discovery of river sharks in Western Province for the first time since the 1970s (White *et al*., 2015) was another important finding. The speartooth shark records from Daru represent the first adult specimen of that species recorded, the first verified marine record, and the first pregnant female recorded. These data were unknown prior to our study and given the paucity of data on these species globally, our results drastically improved our understanding of these species in the future. The findings also highlight another important conservation action for PNG as they represent two of the most threatened species of sharks on the planet.

8.1.6 Expansion of the shark and ray collection at UPNG

The large increase in shark and ray specimens in the UPNG fish collection, alongside detailed collection data, will be an important scientific asset for PNG. The specimens represent a large proportion of the biodiversity of sharks and rays in PNG and thus can be utilised as an important teaching resource at UPNG into the future. The renovated shark and ray collection also represents important longstanding material for other shark and ray researchers around the world.

8.2 Capacity impacts – now and in 5 years

8.2.1 Observer training:

The longline fishery and trawl fishery observer data collection manuals (Appendices 1 and 2) provide improved capacity for observers to collect shark and ray specific data. The training workshops held in 2014 reinforced the information, allowed for feedback from the observers and discussed any issues that were raised. This process was very rewarding both for the trainer (WW) and the observers as the questions were very informative and useful and enabled a better understanding of the fishing and observing processes which occur during a fishing trip. Information from the observers led to several changes to the planned data gathering.

The observers used on our project learned a number of new skills which are beneficial for their career development. Some of the observers have been promoted to de-briefers within NFA's observer program. This highlights some longer-term capacity for NFA. The success of the observer program in attaining important biological and species-specific data (and samples) further highlights the need for an ongoing observer program.

8.2.2 Management capacity:

Luanah Yaman (NFA) was awarded a John Dillon Fellowship in 2015 and conducted a training program in Australia in 2016. This training provided Luanah with additional management skills that would have been highly beneficial both for herself in her management role, and for NFA. Unfortunately, Luanah passed away suddenly in early 2017.

8.2.3 Fishery data collection:

Biological processing of the sharks and rays collected by observers provided training opportunities for several PNG project members, most notably Leontine Baje and Benthly Sabub. Leontine was able to transfer these skills directly into her PhD project and Benthly is now able to undertake this work himself and will be able to assist with training of other staff in the future.

Benthly was also involved in the socio-economic data collection during the field surveys to Daru, New Ireland and Manus.

8.2.4 Student focused capacity:

In September 2014, Leontine Baje from NFA was awarded a John Allwright Fellowship to undertake a Masters project at JCU in Townsville. Leontine commenced this project in July 2015 and in mid-2017 was successful in upgrading her Masters to a PhD which is due to be completed in mid-2018. Leontine's project includes development of new skills, e.g. dietary analyses, age and growth determination, and performing ecological risk assessments. Furthermore, these represent new skills for NFA and upon completion of her PhD, Leontine will be the first NFA staff member to have been awarded a PhD. This represents a significant capacity boost for NFA and elevates Leontine as potential major project leader for NFA which will have a positive long term impact for NFA.

Two Australian PhD students were involved in this project. Jonathan Smart (JCU) undertook his PhD on the life history and demographic analyses of two key shark species. Jon was awarded his PhD in late 2016 and in early 2017 secured a permanent position as a fisheries modeller at the South Australian Research and Development Institute (SARDI). The skills he developed on this project provided him with the skills to secure this highly competitive permanent position. Jon was also instrumental in training other students involved in this project, including Leontine and the other JCU students (see below). Madeline Green (UTas) commenced her PhD in early 2015 and is due to submit in mid-2018. The resources available to Madi for her PhD have enabled her to explore new techniques, including next generation genomic techniques, which has provided her with the skills to be highly competitive in the genetic field.

The project has also support several other students through JCU in Townsville. Brooke D'Alberto completed a Masters project on age and growth of a key shark species. The skills she developed enabled her to secure a PhD project which she is soon to commence at JCU. Michael Grant completed an Honours project on age and growth of a key shark species, and also has been able to use these skills to secure a PhD project at JCU which he commenced in mid-2017. Sushmita Mukherji is currently undertaking a Masters project on age and growth of another key shark species.

A small Crawford fund project was developed in 2016 which enabled training for Dr Ralph Mana and a potential UPNG student (William Tamarau) on life history of sharks (at JCU) and on biodiversity and collection techniques (CSIRO). This short training workshop provided information and basic skills necessary to begin to develop Honours projects through UPNG using samples collected during this project. Unfortunately William left UPNG shortly after returning and did not commence an Honours project. Another UPNG student, Nigel Mapmani, was invited on the final coastal fisheries survey trip to the East Sepik. This provided him with training on field data collection and biological processing skills. Nigel is due to commence an Honours project using some of this data and planning more trips to the Sepik region. This project will cover his tuition and boarding fees in PNG and a separate but a related project funded by the Save Our Seas Foundation is covering field expenses to allow this project to occur.

8.2.5 Stock assessment component:

Rik Buckworth (CSIRO) and Colin Simpfendorfer (JCU) provided training and mentoring to Jonathan Smart on various demographic modelling and stock assessment techniques. These analyses have led to two publications to date and several others in preparation, as well as providing Jon with the necessary skills which led to him obtaining a permanent fish modeller position at SARDI.

8.2.6 UPNG fish collection upgrading:

A large amount of materials and equipment was brought into the fish collection at UPNG to upgrade the existing collection. This included more than 20 new drums, >500 jars, a large (~500L) plastic container with trolley, >800 L of ethanol, and new labels for specimens. The new infrastructure provided will halt the further degradation of the specimens which was a major issue prior to the project.

8.3 Community impacts – now and in 5 years

Allowing for improved and informed management of PNG's shark resources is the prime mechanism through which the project will have positive impacts on PNG communities. For this reason, the community impacts that eventuate from the project will occur after management changes have been undertaken and may take time to eventuate. The production of an ACIAR Policy Brief (Appendix 32), highlighting the management options for NFA to consider in the future is the first step in achieving such community impacts.

8.3.1 Economic impacts

The main aim of the project was focused on ensuring PNG's resources are managed sustainably. By maintaining its natural resource base, this in itself will have positive impacts on PNG's future income earning potential.

The socio-economic component of the project provided information about how shark resources contribute to the incomes of coastal communities across PNG and how this contribution compares to alternative sources of income. This information will allow management changes that are guided by the biological and stock assessment components of the project to be better tailored to ensure that any negative impacts on income, and overall community welfare, are minimised.

A preliminary recommendation of the socio-economic component of the project is to develop alternative and additional income generating livelihoods for coastal fishing communities (such as finfish fishing and seaweed farming). This could support a move to more sustainable small-scale harvesting of shark resources. If such recommendations are pursued by the NFA and diversification of community incomes can be achieved, there is a potential to not only increase income levels but also reduce the income risks that communities are exposed to.

Data that have been collected on shark fin supply chains may also allow the identification of opportunities to improve market access, product quality and overall resource rent capture by fishing communities (rather than processors and exporters). If this can be achieved, the monetary benefits generated by shark resources may become more evenly distributed across PNG.

8.3.2 Social impacts

The socio-economic component of the research made preliminary recommendations that are intended to improve shark management while also maintaining and diversifying livelihoods to allow more secure food, employment and income opportunities. This provides communities with a greater ability to realise opportunities for improved standards of living, including improved education and health. Traditional gender roles in PNG mean that the pursuit of alternative livelihood opportunities in activities such as seaweed farming and fish processing, recommended as part of the project, can be of particular benefit to women.

One recommendation to come out of the socio-economic project component was to consider the use of community-based fishing rights for sharks. If pursued, such an intervention has previously been shown to increase community engagement in the management of resources, increase community knowledge around natural resources and increase social cohesion and social capital.

While the Milne Bay socio-economic case study did not identify any cultural and spiritual values associated with shark resources, such values were observed in Manus Island and New Ireland. This information will allow improved management of shark resources in these areas to more appropriately manage impacts on such cultural values.

8.3.3 Environmental impacts

The long-term goal of the project was to ensure the sustainable impact of fisheries on sharks and rays. Conservation and biodiversity information for sharks and rays produced during the project will help produce a strong biodiversity baseline for sharks and rays in PNG. This data will be crucial for a variety of environmental and conservation studies in the future.

8.4 Communication and dissemination activities

8.4.1 Conferences

Conferences were considered an important way to disseminate results to the broader scientific community. Not only did this disseminate the project results, it also provided project staff with exposure to other experts in the field.

- 60th AARES (Australian Agricultural and Resource Economics Society) Annual Conference (Canberra, February 2016)
  - Shark fishing in the Louisiade Archipelago, Papua New Guinea Socioeconomic characteristics and policy options (S. Vieira)
- American Elasmobranch Society annual conference (New Orleans, July 2016)
  - Oral presentation: *Preliminary Investigation into Sawfish Catches in Papua New Guinea* (W. White)
  - Oral presentation: *Connectivity of Narrow sawfish (*Anoxypristis cuspidata*) in the Indo-Pacific* (M. Green)
- Australian Society of Fish Biology and Oceania Chondrichthyan Society joint conference (Hobart, September 2016)
  - Oral presentation: *Age, growth and maturity of oceanic whitetip sharks (*Carcharhinus longimanus*) from Papua New Guinea* (B. D'Alberto)
  - Oral presentation: *Stochastic demographic analyses of the silvertip shark (*Carcharhinus albimarginatus*) and the common blacktip shark (*Carcharhinus limbatus*) from the Eastern Indo-Pacific* (J. Smart)
  - Oral presentation: *Variability in multiple paternity rates for grey reef sharks (*Carcharhinus amblyrhynchos*) and scalloped hammerhead sharks (*Sphyrna lewini*) in Papua New Guinea* (M. Green)
  - Oral presentation: *Sawfish in Papua New Guinea: what we know and where to next* (W. White)
  - Poster presentation: *Age and growth of the silky shark* Carcharhinus falciformis *from Papua New Guinea* (M. Grant)
  - Keynote presentation: *Piecing together a living puzzle: biogeographic patterns in some shallow water sharks and rays in New Guinea* (W. White)
- Indo-Pacific Fish Conference (Tahiti, October 2017)
  - Life history of two pelagic sharks from Papua New Guinea (D'Alberto)
- Oceania Chondrichthyan Society conference (Stradbroke Island, February 2018)
  - Oral presentation: *Life history of scalloped hammerhead sharks,* Sphyrna lewini, *from Papua New Guinea* (B. D'Alberto)
  - Oral presentation: *Connectivity affected by physical barriers and sex-biased behaviours for the silvertip shark (*Carcharhinus albimarginatus*)* (M. Green)
  - Oral presentation: *Life history of the blue shark (*Prionace glauca*) from Papua New Guinea, including an approach to estimate the required number of samples for back-calculation techniques* (S. Mukherji)
- Sharks International conference (Brazil, July 2018)
  - Oral presentation: *Reef shark connectivity: A case study using multiple genetic markers* (M. Green)

8.4.2 Media related

- NBC PNG Dabai Show live radio and filmed for TV – general project information (W. White, October 2015)
- Radio Manus – socioeconomic survey of the Manus region (S. Vieira, October 2015)
- Various national PNG news outlets – X-ray exhibition in Port Moresby (W. White, September 2016)
- ECOS – Sharks and Rays of Papua New Guinea book (W. White, March 2018, https://blogs.csiro.au/ecos/sharks-and-rays-of-png/)

8.4.3 Meetings and workshops

- Annual coordination meetings – these meetings provided an important means to disseminate project results to date and were a pivotal step in the impact pathway towards sustainable management of PNG's shark and ray resources.
    - Inception meeting (Port Moresby, February 2014)
    - Annual meeting (Hobart, December 2014)
    - Annual meeting (Port Moresby, March 2016)
    - Annual meeting (Hobart, April 2017)
    - Final meeting (Hobart, January 2018)
- Observer training workshop (Rabaul and Port Moresby, February 2014) – training of NFA observers on shark specific data requirements resulted in improved skills of NFA observers to collect more detailed shark specific data and samples. This will be an asset for NFA in the future as more focus shifts on obtaining detailed shark specific data due to international obligations (e.g. conservation issues and FAO reporting);
- Taxonomic and genetics training workshop (Hobart, September 2014) – training of one NFA staff member (Leontine Baje) at the CSIRO Hobart marine laboratories in museum curatorial techniques and basic genetic techniques. Included involvement in a new species description and provided important scientific writing skills. An improved taxonomic understanding better equips NFA with the foundation requirements of all life sciences, accurate taxonomy;
- Project review (Port Moresby, June 2017) – provided a critical review of the progress of the project to ensure it remained on the impact pathway towards improved management of PNG's shark and ray resources;
- Final stock assessment workshop (Hobart, January 2018) – involved the development of management options for NFA to better manage their shark and ray resources into the future. The resulting Policy Brief is an important step forward in evidence-based management for shark fisheries in the region;
- IUCN Red List training and workshop (Townsville, February 2015) – A Crawford Fund project provided funding for an NFA staff member (Leontine Baje) to attend a regional IUCN Red List assessment workshop. This provided international level training of the Red List process, exposure to the main regional experts on sharks and rays, and authorship on some Red List assessments. This training helped develop important conservation management skills which will better equip NFA to deal with unavoidable conservation issues related to sharks and rays in the future.

- Taxonomic, genetic and life history workshop (Hobart and Townsville, February 2017) – A Crawford Fund project provided funding for two UPNG students (Dr Ralph Mana and William Tamarua) to attend a workshop providing basic training of taxonomic, genetic and life history research. The workshop focused on equipment needs and skills required. The main aim of this workshop was to provide a pathway towards establishing Honours projects at UPNG related to this project.

8.4.4 Biodiversity information

The *Sharks and Rays of Papua New Guinea* book provides important information on PNGs shark and ray biodiversity. To maximise dissemination of these findings, close to 200 copies were distributed to relevant people and organisations and an electronic version (PDF) is also freely available for download from the ACIAR website (http://aciar.gov.au/node/25521). In PNG, these included fisheries officers, university staff, dive operators, sports fishing agencies, etc.

8.4.5 Social media related

- A Twitter account was set up called @PNGSharksRays in late 2017. It has a total of 152 followers and has been used to disseminate some of the scientific findings of the project using visual media to increase dissemination to a wider audience.
- A Facebook page (www.facebook.com/sharksPNG), aimed initially at divers and dive industry people to share images of various sharks and rays, was established in 2014. It was found to be difficult to maintain and didn't reach the desired audience so it was not utilised to any great extent towards the end of the project unfortunately. As a result only 52 followers, but it did create a forum for sharing of related videos between PNG organisations, e.g. Walindi Dive.

8.4.6 Other

- An X-ray exhibition was organised in September 2016. Six digital x-rays of various PNG sharks and rays were printed on high quality aluminium and an exhibition held at the Australian High Commission in Port Moresby. Two high school groups were invited to attend and following formalities, a number of specimens from the UPNG fish collection were shown to the students and time for questions was provided for the school groups to find out more about PNG sharks and rays;
- In May 2017 and March 2018, two groups of PNG nationals involved in a month-long project management course at the Institute of Project Management in Hobart visited the Australian National Fish Collection in Hobart. During both of these tours, the findings of this project were outlined to the participants (~50 in total) while showcasing specimens of sharks and rays from PNG collected during the project. While not directly related with fisheries in most cases, the linkage with livelihoods of fishing communities in the provinces surveyed in our project were of particular interest to the groups and many left inspired by the work being conducted by NFA and CSIRO in PNG.

9 Conclusions and recommendations

9.1 Conclusions

This project highlighted the importance of a good fisheries observer program in PNG. The data obtained by the observers in the longline and trawl fisheries enabled the following information to be collected and analysed:

1. Age and growth and reproductive biological data on more than 8 key species of sharks;
2. Images and genetic samples to facilitate verification of species identification;
3. Genetic samples from 3 key species to determine the population structures of these species in the broader region and to assess connectivity;
4. Genetic samples from 2 key species to determine the extent of multiple paternity in their populations;
5. Accurate catch data enabling generation of accurate CPUE estimates and detailed characterisation of the fisheries;
6. Validated species composition data which fed into the biodiversity components;
7. Demographic analyses made possible by the data collected above.

Thus, the observer program was critical for the majority of objectives of this project and it highlights the importance of maintaining a national observer program.

Analyses of the catch and effort data from the fisheries examined in this project were used to generate the first accurate estimates of total shark and ray landings for PNG. Given that PNG reporting to FAO is considered very poor, these figures are very important.

The importance of shark and ray catches in coastal fisheries to communities and livelihoods in some provinces was highlighted in this project. The project also found that market chains for shark fin were highly dependent on those of sea cucumbers, highlighting a need to monitor changes in the sea cucumber fishery in order to understand the coastal fisheries for sharks and rays.

A more comprehensive understanding of the biodiversity of sharks and rays in PNG was also obtained, particularly for deep-water species. This forms an important biodiversity baseline data set for PNG which can be used to assess future change.

Development of a series of management options for NFA related to managing their shark and ray resources should have long-term benefits to PNG if adopted.

Capacity building, through students and tools (e.g. shark and ray field guide), proved to be an important component and critical for future benefits to PNG. Project outreach was also an important aspect of the project and when done well, was shown to facilitate data collection on subsequent trips.

9.2 Recommendations

One of the difficulties faced during this project was the limited availability of NFA staff for some components of the project. This could have been overcome if UPNG was included more actively and as a funded agency on the project from commencement. This would have provided access to additional people to work on various project components. Future work should not only involve UPNG more actively, but it should also involve them in the consultation and project development stages.

The socioeconomic component of this project was inadequately resourced during this project, due largely to the underestimation of the importance of the coastal fisheries sector to this project. Future projects on coastal fisheries and/or sharks and rays needs to include more comprehensive social and economic components to allow for capacity building of PNG staff and to generate more comprehensive datasets.

Although a Policy Brief was developed and management options proposed, the planned final workshop in PNG, which was aimed at fisheries managers and decision makers, was moved to Hobart with only a single PNG staff member in attendance. While this could not be avoided in the current project, future projects need to ensure better coverage of PNG staff, possibly by locking in dates early in the project for critical meetings and workshops.

To strengthen relationships with stakeholders, project information should be delivered through a variety of means, including talks, radio interviews, pamphlets, posters etc. With the amount of information produced during this project, outreach material should be produced prior to, or in conjunction with, future research.

This project was well placed to provide significant input into a National Plan of Action for sharks in PNG. Although some talks were held within NFA to develop their NPOA, this project was not engaged to assist or provide information to the process. Future projects should assist with the NPOA process and help drive it to implementation.

Given the importance of biological collections, the significant effort put into upgrading and expanding the national fish collection at UPNG should be continued. Although there are costs in maintaining a biological collection, a well-maintained biological collection can be cost effective when one considers the cost of collecting such material for specific projects if the need arose.

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11 Appendixes

11.1 Appendix 1:

Appendix 1. Manual for data collection and species identification of sharks from longline vessels in Papua New Guinea – observer training guide (W. White and L. Baje).

Appendix 2. Manual for data collection and species identification of sharks and rays from prawn trawl bycatch in Papua New Guinea – observer training guide (W. White, L. Baje and S. Appleyard).

Appendix 3. PNG longline observer (modified) LL-4 form – Shark monitoring (W. White, L. Baje and S. Appleyard).

Appendix 4. PNG trawl observer form (modified from SPC LL-4 form) – Shark and ray monitoring (W. White and L. Baje).

Appendix 5. Shark fin buyer survey – socioeconomic datasheet (S. Vieira).

Appendix 6. Shark fisher survey – socioeconomic datasheet (S. Vieira).

Appendix 7. Diver information sheet - Sharks and rays of Papua New Guinea (W. White).

Appendix 8. Guide to the sharks and rays of Papua New Guinea – species possibly encountered by divers (W. White).

Appendix 9. Sampling for shark genetics – FTA elute cards (S. Appleyard and W. White).

Appendix 10. Smart et al. 2016. Effects of including misidentified sharks in life history analyses: a case study on the Grey Reef Shark *Carcharhinus amblyrhynchos* from Papua New Guinea. PLoS One 11, e0153116.

Appendix 11. Smart et al. 2017. Life history of the silvertip shark *Carcharhinus albimarginatus* from Papua New Guinea. Coral Reefs 36, 577–588.

Appendix 12. D'Alberto et al. 2017. Age, growth and maturity of oceanic whitetip shark (*Carcharhinus longimanus*) from Papua New Guinea. Marine and Freshwater Research 68, 1118–1129.

Appendix 13. Grant et al. 2018. Life history characteristics of the silky shark *Carcharhinus falciformis* from the central west Pacific. Marine and Freshwater Research 69, 562–573.

Appendix 14. Baje et al. in review. Age, growth and maturity of the Australian Sharpnose Shark *Rhizoprionodon taylori* from the Gulf of Papua. PLoS One.

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Appendix 16. White et al. in prep. Elasmobranch bycatch in the demersal prawn trawl fishery in the Gulf of Papua in Papua New Guinea. In prep – figures and tables.

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Appendix 19. Appleyard et al. 2018. Artisanal shark fishing in Milne Bay Province, Papua New Guinea: biomass estimation from genetically identified shark and ray fins. Scientific Reports 8(6693), 1–12.

Appendix 20. Vieira et al. 2017. Artisanal shark fishing in the Louisiade Archipelago, Papua New Guinea: socio-economic characteristics and management options. Oceans & Coastal Development 137, 43–56.

Appendix 21. A summary of the available data on shark fishing activities in Papua New Guinea (S. Vieira and L. Yaman).

Appendix 22. Training report for Crawford Fund project: Age and growth determination in fishes and curatorial training for museum collections (R. Mana & W. White).

Appendix 23. White et al. 2016. *Rhinobatos manai* sp. nov., a new species of guitarfish (Rhinopristiformes: Rhinobatidae) from New Ireland, Papua New Guinea. Zootaxa 4175, 588–600.

Appendix 24. White et al. 2016. *Galeus corriganae* sp. nov., a new species of deepwater catshark (Carcharhiniformes: Pentanchidae) from Papua New Guinea. Zootaxa 4205, 255–264.

Appendix 25. White W.T. et al. 2017. A new species of velvet skate, *Notoraja sereti* n.sp. (Rajiformes: Arhynchobatidae) from Papua New Guinea. Zootaxa 4244, 219–230.

Appendix 26. White et al. 2017. *Etmopterus samadiae* n. sp., a new lanternshark (Squaliformes: Etmopteridae) from Papua New Guinea. Zootaxa 4244, 339–354.

Appendix 27. White et al. 2017. Description of a new species of deepwater catshark *Apristurus yangi* n.sp. (Carcharhiniformes: Pentanchidae) from Papua New Guinea. Zootaxa 4320, 25–40.

Appendix 28. Green et al. 2018. Mixed-marker approach reveals varying levels of genetic connectivity in populations of Narrow Sawfish (*Anoxypristis cuspidata*) in Australia and Papua New Guinea. Endangered Species Research, in press.

Appendix 29. Green et al. 2017. Variability in multiple paternity rates for grey reef sharks (*Carcharhinus amblyrhynchos*) and scalloped hammerheads (*Sphyrna lewini*). Scientific Reports 7, 1528.

Appendix 30. Population genetics of three key shark species in PNG – preliminary result figures.

Appendix 31. Smart et al. 2017b. Stochastic demographic analyses of the silvertip shark (*Carcharhinus albimarginatus*) and the common blacktip shark (*Carcharhinus limbatus*) from the Indo-Pacific. Fisheries Research 191, 95–107.

Appendix 32. Draft Policy Brief (text only) - Sustainable shark and ray fisheries in Papua New Guinea.

Appendix 33. Taxonomy and genetic workshop – training and protocol guide (W. White, S. Appleyard and L. Baje).

Appendix 34. White et al. 2016. *Aetomylaeus caeruleofasciatus*, a new species of eagle ray (Myliobatiformes: Myliobatidae) from northern Australia and New Guinea. Ichthyological Research 63, 94–109.

Appendix 35. Images of the fish collection cleaning day organised by the University of PNG and funded by NFA.

Appendix 36. White W.T. and Ko'ou A. 2018. An annotated checklist of the chondrichthyans of Papua New Guinea. Zootaxa 4411, 1–82.

Appendix 37. Last et al. 2016. Status of maskrays of the *Neotrygon kuhlii* species complex (Myliobatoidei: Dasyatidae) with the description of three new species from the Indo-West Pacific. Zootaxa 4083, 533–561.

Appendix 38. Last et al. 2016. *Urogymnus acanthobothrium* sp. nov., a new euryhaline whipray (Myliobatiformes: Dasyatidae) from Australia and Papua New Guinea. Zootaxa 4147, 162–176.

Appendix 39. Last et al. 2016. Three new stingrays (Myliobatiformes: Dasyatidae) from the Indo–West Pacific. Zootaxa 4147, 377–402.

Appendix 40. White et al. 2017. Revision of the genus *Centrophorus* (Squaliformes: Centrophoridae): Part 2 — Description of two new species of *Centrophorus* and clarification of the status of *Centrophorus lusitanicus* Barbosa du Bocage & de Brito Capello, 1864. Zootaxa 4344, 86–114.

Appendix 41. Finucci et al. G.J.P. 2018. Redescription of *Hydrolagus ogilbyi* (Chimaeriformes; Chimaeridae) from the Indo-Australian region. Zootaxa 4375, 191–210.

Appendix 42. White et al. 2018. Sharks and rays of Papua New Guinea. ACIAR Monograph No. 189. Australian Centre for International Agricultural Research: Canberra.

Appendix 43. White et al. in prep. The target shark longline fishery in Papua New Guinea. In prep – figures and tables.

Appendix 44. Mukherji 2017. Age and growth of blue sharks (*Prionace glauca*) from Papua New Guinea. Minor report for MSc, James Cook University, 41 pp.