# ECOLOGICAL CHARACTERISTICS AND MANAGEMENT OPTIONS FOR SMALL SCALE FISHERIES IN NEW IRELAND PROVINCE


**A REPORT OUTLINING ECOLOGICAL CHARACTERISTICS AND MANAGEMENT OPTIONS FOR SUSTAINABLE SMALL SCALE FISHERIES IN NEW IRELAND PROVINCE, PAPUA NEW GUINEA**

WILDLIFE CONSERVATION SOCIETY

WCS Papua New Guinea programme

## WILDLIFE CONSERVATION SOCIETY

The Wildlife Conservation Society saves wildlife and wild places worldwide. We do so through science, global conservation, education and the management of the world's largest system of urban wildlife parks, led by the flagship Bronx Zoo. Together these activities change attitudes towards nature and help people imagine wildlife and humans living in harmony. WCS is committed to this mission because it is essential to the integrity of life on Earth.

## WCS PNG PROGRAMME

The Wildlife Conservation Society Papua New Guinea programme (WCS PNG) is the longest established international conservation NGO within Papua New Guinea. WCS PNG works with local communities, local and international NGOs, and with local, provincial and national governments on a wide range of conservation issues and across a range of landscapes from the country's coral islands to its forested highlands.

The vision of WCS PNG is "*Gutpela sindaun, gutpela solwara, gutpela bus*"

which translates to "*Empowered people with healthy forests and seas*"

*Front Cover Photo:* Smoked fish on sale in Kavieng New Ireland Province, by Kate Holmes.

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For further information contact:

Sven Frijlink (sfrijlink@wcs.org) or Richard Cuthbert (rcuthbert@wcs.org)

WCS PNG Programme, PO Box 277,

Goroka, Eastern Highlands Province,

Papua New Guinea

# EXECUTIVE SUMMARY

The Wildlife Conservation Society (WCS) recently commenced a project to improve capacity in managing selected small-scale fisheries at the community level in New Ireland Province, Papua New Guinea (PNG). In order to better understand local fisheries issues and frame research and management needs for the project, a meeting of participating community representatives and other stakeholders was held in Kavieng, New Ireland in February 2014. A key focus of the meeting was the identification of locally important fisheries that have experienced sustainability challenges. While many species and species groups were identified, five species groups were most prominent in this regard – trevallies (Carangidae), rabbitfishes (Siganidae), mud crabs (Scylla sp.), spiny rock lobsters (Paniluridae) and shellfish (primarily trochus [Trochus niloticus] and green snails [Turbo mamoratus]). In accordance with the goals of the Packard small-scale fisheries project, three of these five species groups were required to be short-listed for research, education and management efforts. The primary objective of this report was to identify the three species groups most amenable to small-scale community based management in the New Ireland Province. Secondary objectives were the identification of 'most preferred' management options for short-listed species and knowledge gaps requiring local research to better guide management efforts.

In selecting candidate groups for the project, the characteristics of both small-scale management and candidate species groups were considered. To do this, a review of literature pertaining to the ecology, life history and relevant management outcomes of candidate species was undertaken. The selection process assessed the potential effectiveness of specific management options (i.e. closed areas, size limits, gear restrictions etc) able to be implemented in a small-scale community context. In effect therefore, management options described as having success potential were those deemed to be a 'good fit' between available information on species ecology and life history and the capacity of community based management to deliver beneficial conservation and livelihood outcomes in this regard.

The three species groups chosen were mud crabs, shellfish and rabbitfish. While the Project will primarily focus efforts on these three groups, future management interventions relating to trevallies and rock lobsters may also be considered for inclusion into management plans or other management instruments if resources permit. However, research efforts guiding management options will be restricted to mud crabs, shellfish and rabbitfish. A summary of the suitability of each group to small-scale management, preferred management options and research needs is presented below.

*Trochus* While the sessile nature of these highly valued animals makes them vulnerable to exploitation, their limited mobility and short larval phase makes them amenable to localised management. A nationally imposed slot limit applies to *Trochus*; however, anecdotal reports suggest that education and awareness efforts are required to encourage greater compliance. Fully protected (*tambu*) areas for *Trochus* broodstock are also recommended due to the short duration of larval dispersal enabling recruitment to occur close to spawning sites. This course of action is also recommended for green snails.

*Mud Crabs* Characteristics of the mud crab fishery that facilitate the effectiveness of small scale management include the localisation of mangrove habitats, the limited movements of crabs post-settlement, the economic and cultural importance of crabs to mangrove based communities, and the availability of relatively simple and potentially effective management options. Preferred management options are the implementation of minimum size limits, a prohibition on the harvest of berried females and the protection of mangrove habitats. However, local research is required to gain a better understanding of size at sexual maturity, spawning seasonality, spawning migrations distances for female crabs, rates of growth and natural mortality and the impact of current harvesting practices on mangrove habitats.

*Rabbitfish* The herbivorous rabbitfish support important local subsistence and artisanal fisheries and are important in keeping coral free from algal domination. The life history characteristics of rabbitfish, including a fast growth rate, short life span and high turnover rate suggest that they will respond rapidly to effective management interventions. However, given the diversity in habitat occupation and ecological roles among rabbitfish, management efforts should be species or guild specific. In particular, efforts should focus on the predominant *Siganus lineatus* and possibly other seagrass associated species such as *S. argenteus* and *S. fuscesens*. The preferred management options are are gillnet mesh size reductions and periodic closures of spawning sites. To guide the implementation of management efforts, local research should focus on species-specific fishery trends, gear selectivity, the location of spawning aggregation sites, and species' home ranges and site fidelity.

*Trevally* The low degree of site fidelity of these highly mobile long ranging fish, coupled with their non-ubiquitous distribution poses challenges for the management of trevally at a community level. Nonetheless, the preferred management options are gillnet mesh size reductions and periodic closures of spawning sites if they are identified within the tenure of participating communities.

*Rock Lobster* The exceptionally long periods of larval dispersal effectively preclude local management efforts in repopulating local reefs as 'source' areas are generally located a long way from 'sink' areas. Despite this, there are ways in which communities may maximise the value of lobsters recruited to local reefs. Fortunately, the most obvious measure –which is potentially the most effective measure – is relatively straightforward: encourage compliance with national regulations on size limits. Encouraging compliance with catch prohibitions on berried females is also recommended.

A significant limitation to the management of these fisheries at a community scale is a mismatch with the geographic scales that encompass their life histories. The broader scale management of multiple adjacent communities would expand the geographic scales necessary to apply effective management controls for species that occupy habitats beyond those under the tenure of individual communities. Such an approach would also make management measures that impose catch constraints more attractive to implement through a system of management 'trade-offs' between participating communities. Given the greater potential for successful conservation and livelihood outcomes compared to working with 'isolated' communities, management arrangements encompassing multiple adjacent communities should be pursued for this Project.

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# 1. INTRODUCTION

The coral reefs of Papua New Guinea (PNG) are among the most species diverse in the world (Hughes et al., 2002) and support important artisanal and subsistence fisheries. Compared to other nations within the Coral Triangle such as Indonesia, Malaysia and the Philippines, they are relatively underexploited (Huber, 1994). Despite the comparative health, studies have indicated localised fishery declines, particularly in fisheries with access to cash markets (Huber, 1994). These declines have been attributed to growing population pressures, technological advancements and greater access to markets (McClanahan, 2006; Cinner and McClanahan, 2006).

While PNG has government fisheries regulations pertaining to some species they are seldom enforced (Huber, 1994) and generally do not apply to subsistence fisheries. Overall, the fishery is small scale and dispersed and multiple gears such as gill nets, hook and line, spear guns and derris root catch a high variety of species. Fisheries management is based on highly decentralized marine tenure institutions that are generally not coordinated over large scales (McClanahan et al., 2006). While the management of marine resources under often exclusive community tenure provides incentives for sustainable management practices (Hardin, 1968), communities often lack the knowledge, resources and external linkages to do so.

These challenges create a need to develop simple management heuristics that can be utilized by local community leaders (Prince, 2003; McClanahan and Cinner, 2008). Such needs are enshrined in national legislation, which provides legal recognition of rights to customary management by local communities (Hyndman, 1993). Traditional fisheries management practices may include area closures, gear restrictions and restricting some fishing activities to endowed individuals (Johannes, 2002; Cinner et al., 2005; 2006). Customary resource management is generally informed by local ecological knowledge and is underpinned by negotiating resource access by community leaders and resource owners. Negotiations are usually based on local politics, community needs, and knowledge of the environment (McClanahan and Cinner, 2008). Therefore, effective resource co-management interventions enabled by the assistance of external organisations will need to reflect existing traditional management regimes and be able to be understood, justified, and enforced at the local level (Drew, 2005).

To date, a significant portion of fisheries co-management efforts in the region have focussed on marine protected areas. While protected areas are recognised by customary management regimes (known locally as 'tambu' sites), and have resulted in some successful outcomes (Jenkins et al., 2006; Cinner et al., 2006), others have failed to produce tangible benefits (McClanahan, 1999; WCS unpublished data). Though numerous socioeconomic factors are implicated in the success or failure of protected areas (McClanahan et al., 2006), there is often a large discrepancy between the size of community managed reserves and the spatial requirements of marine species. For example, in a PNG study, Jenkins et al. (2006) reported that protected areas were effective in increasing the abundance of site-attached species but not effective in conserving highly mobile species. As well as having potential to protect sessile or site attached species, protected areas have proven to be effective in PNG in protecting marine organisms during vulnerable life stages, such as spawning aggregations (Hamilton et al., 2011). However, given the species-based limitations associated with community scale protected areas, other management interventions such as harvest and gear restrictions may need to be considered (Cinner et al., 2006).

In the current study, The Wildlife Conservation Society (WCS) is working with partners to improve local level capacity to manage selected small-scale fisheries in Papua New Guinea. Building on previous work with communities in fostering marine conservation in New Ireland Province, the project will focus on improving the management of three locally important species groups across a set of communities in New Ireland with the overall goal of developing a model for successful collaborative fisheries management that fully engages the local communities who depend on the sustainability of these fisheries. In order to frame the research and management needs for the project, the Wildlife Conservation Society (WCS) convened a meeting of stakeholders from coastal New Ireland communities interested in collaborating with WCS in their small-scale community based management project in February 2014. During the meeting, five groups of species of marine organisms were identified as being most important to stakeholders, many of whom were artisanal and/or subsistence fishers. The five species groups were trevallies (Carangidae), rabbitfishes (Siganidae), mud crabs (*Scylla* sp.), spiny rock lobsters (Paniluridae) and shellfish (primarily trochus [*Trochus niloticus*] and green snails [*Turbo mamoratus*]).

It is the primary aim of this report to narrow down the five species groups identified during the stakeholders meeting to three species groups most suitable for community based management in New Ireland. In doing so, the characteristics of both community based management options (as opposed to fisheries management at a different scale) and candidate species groups (in particular, their ecological characteristics) will be considered. In effect therefore, management options will be determined as having success potential if they are deemed to be a 'good fit' between available information on species ecology and life history and the capacity of community based management to deliver beneficial conservation and livelihood outcomes in this regard. Species groups with greatest potential for local scale management options will be the most suitable candidates for implementing management solutions in New Ireland in the coming years. Secondary aims for this report are to identify the 'most preferred' management options for short-listed species and knowledge gaps requiring local research to better guide management efforts

# 2. METHODS

A literature review was undertaken to source information relevant to potential management interventions for the five species groups identified during the small-scale fisheries stakeholders meeting in February 2014. The sourcing of literature may be thought of as a twostep process. For the first step, local information (mainly pertaining to New Ireland Province [NIP]) was collected relating to the results of species management interventions (if available), and the local status and viability of species groups. The latter included ecological assessment reports and the results of market surveys. Documents were primarily accessed through the Wildlife Conservation Society and the National Fisheries College in Kavieng.

The second step of the literature review involved the sourcing of non-local materials relating to the results of small-scale fisheries management measures and ecological characteristics for the five species groups. The literature search was conducted using Google Scholar and Aquatic Science and Fisheries Abstracts Database (ASFA). Some information was also obtained through direct communication with researchers.

# 3. RESULTS AND DISCUSSION

The following sections detail the ecology and fisheries management options for each species group in turn.

## 3.1 TREVALLY

### 3.1.1 Fisheries information

The Carangidae family contains approximately 200 different species of trevallies, jacks and scads distributed in all oceans (SPC, 2011). Carangids are a diverse family of reef and lagoon fish which are important in the subsistence and artisanal fisheries of New Ireland. In a rapid ecological assessment of northern New Ireland conducted by the Nature Conservancy in 2007, Carangids were the fifth most prominent group of 'food fishes' (fishes that were deemed to be important to local fishers for personal consumption or sale) observed, representing around 5% of fish by numbers (Hamilton et al., 2009). In terms of biomass, trevallies were the third most prominent food fish group in the region, comprising around 13.5% of total fish biomass. While Hamilton et al., (2009) identified 13 carangid species in their assessment, they suggested that the following seven species are of greatest importance to regional communities in New Ireland and Manus Island:

| | |
|---|---|
| *Carangoides bajad* | Orange-spotted trevally |
| *Carangoides plagiotaenia* | Barcheek trevally |
| *Caranx ignobilis* | Giant trevally |
| *Caranx melampygus* | Bluefin trevally |
| *Caranx sexfasciatus* | Bigeye trevally |
| *Elagatis bipinnulatus* | Rainbow runner |
| *Gnathanodon speciosus* | Golden trevally |

Hamilton et al (2009) reported relative biomass and abundance of trevallies around Manus Island to be much lower than that for New Ireland. This is likely to reflect the relative suitability of both regions in supporting trevally populations rather than overfishing in Manus Province as the relative densities of other large targeted reef fish such as wrasses, parrotfishes and groupers were much higher in Manus Province that in New Ireland Province (Hamilton et al., 2009).

Two studies conducted by the National Fisheries Authority (NFA) in 2004 also demonstrated the importance of trevallies, known locally as *batbat*, to New Ireland communities (NFA 2005a, 2005b). A survey of fish landings revealed that 9% of all fish caught, by numbers, were carangids (NFA, 2005a). Three carangids of greatest importance to fishers were the bluefin trevally, bigeye trevally and rainbow runner. The same study also revealed that carangids were the third highest represented fish group for sale at Kavieng markets.

McClanahan and Cinner (2008) conducted a study on gear selectivity on reef associated species at ten sites in PNG, including three sites near Kavieng in NIP. Overall, the ten species of Carangids comprised around 9, 6 and 2% of the total catch using lines, nets and spearguns, respectively. As analyses were conducted on pooled data between regions, the species caught at the three NIP sites are not able to be identified. Nonetheless, four of the Carangids identified by Hamilton et al. (2009) as being important for NIP communities (*Caranx nobilis, C. melampygus, C. Sexfasciatus, Elegatis bipinnulatus*) were recorded.

### 3.1.2 Ecology

Most trevallies live in a wide range of off shore and inshore habitats including coral reefs. Juveniles are sometimes found in brackish water near estuaries, and often utilise mangroves as nursery areas (Wantiez and Kulbiki, 2009). Adult trevallies may be solitary or schooling; this also applies to individual species (Thresher and Gunn, 1986). While the Carangidae family contains approximately 200 species, most are highly mobile with limited site attachment.

Trevallies are fast-swimming fish that hunt for small fish (Potts, 1981), though some species dig in the sea floor for worms, shrimps, crabs and other invertebrates (SPC, 2011). Within the Caragnid Family, hunting behaviour was been observed during both the day and night, and at various depths, including the seabed (Potts, 1981; SPC, 2011). Ogden and Zieman (1977) further report that some reef-dwelling trevallies are opportunistic nocturnal feeders – they are largely inactive during the day, taking refuge within the reef but may be activated into hunting in the presence of baitfish schools.

In a mark-recapture survey of reef-attracted fish, less than 2% of Carangids (*Cananx latus, C. ruber*) were recaptured from a reef site, compared with an average of 46% for all species studied (Chapman and Kramer, 2000). This suggests a low degree of site fidelity and high degree of mobility for these species.

### 3.1.3 Reproduction and Life Cycle

Trevallies have separate sexes. Many common species appear to reach reproductive maturity at lengths between 35 and 56 per cent of their maximum size (SPC, 2011). For example, *Caranx ignobilis* grows to about 160 cm and 80 kg over a lifespan of about 24 years and reaches reproductive maturity at a length of about 60 to 95 cm when they are between 3 and 5 years old (SPC, 2011). The smaller *Caranx melampygus*, which grows to 90 cm, reaches sexual maturity at between 30 and 40 cm at an age of about 2 years (SPC, 2011).

Many trevally species travel long distances to breed in large numbers at spawning aggregations (Nagelkerken, 2009). The areas at which they gather (spawning sites) are often at the outer edge of fringing reefs or near reef passages (Hamilton and Walter, 1999). These aggregations often occur as waters become warmer and at times are related to the cycle of the moon (Hamilton and Walter, 1999; Nagelkerken, 2009; SPC, 2011). While information on the number of individuals is scare, and is likely to vary between species and location, Nagelkerke (2009) reports that spawning aggregations of bigeye trevally can consist of over 1500 individuals

Trevallies are broadcast spawners: females release their eggs into the water which are fertilised by males. The fertilised eggs hatch into larvae that drift in the sea for periods often greater than a month. Less than one in a thousand larvae survive to become a juvenile (SPC, 2011). Juveniles often enter inshore shallow water and move out to deeper reefs as they grow (Smith and Parish, 2002). Less than 1% of juveniles survive the 2 to 5 years that it takes to attain adulthood (SPC, 2011).

### 3.1.4 Management Measures and Options

Community representatives at the February Small-Scale Fisheries Stakeholder Meeting identified nine potential options for trevally management in NIP:

1. Encourage/enforce minimum mesh sizes
2. Impose limits on catch numbers
3. Protect mangrove and coral habitats. The latter includes the prohibition of coral removal for lime production
4. Prohibit (or encourage compliance with existing prohibition of) the use of destructive fishing practices such as derris root and explosives
5. Investigate means (such as buffer zones along waterways) of restricting damage to aquatic habitats by chemical fun-off from oil palm plantations
6. Investigate means of restricting damage to aquatic habitats by siltation fun-off from logging operations. Options raised included buffer zones along waterways, seeking compensation for illegal practices (and using proceeds for habitat restoration)
7. Conduct/access biological/ecological research including species life cycles, size at maturity and the identification of important habitats and life stages

The first three options were identified as 'most preferred'. These options will be discussed in view of available literature on sustaining small-scale mud trevally fisheries and dependent livelihoods.

*Harvest Restrictions*

According to the SPC (2011), authorities in several Pacific Island countries have imposed minimum size limits for trevallies (variously 25 to 30 cm fork length). Although separate minimum sizes have sometimes been used for scads and smaller trevallies, in many cases the particular species of trevally to which the minimum size regulations apply has not been stated (SPC, 2011). Taking into account the variation in sizes of different species, a 'one size fits all' minimum size may not allow larger species to reach breeding size and would be overly restrictive for some smaller species. To be effective, size limits should be applied to individual species. However, this may be excessively restrictive for communities in areas frequented by numerous species. Furthermore, given the large ranges occupied by many if not most Carangid species, minimum size limits would need to be adhered to at a scale larger than that occupied by individual communities to be effective.

Based on this, it is anticipated that any effective implementation of size restrictions would require:

- Management uniformity between numerous bordering communities at a spatial scale encompassing the home range of trevally species (from juveniles to adults) deemed important to communities and vulnerable to exploitation.
- A management focus on a few key carangid species; preferably species that are easily identified.

The Stakeholder's Meeting for the Packard fisheries project identified restrictions on catch numbers as a preferred management option. However, there are some considerations that may make this course of action less tenable than other management options discussed in this Section. Firstly, a 'bag limit' or equivalent catch restriction would disadvantage co-operating communities at times when more fish are available to be caught. Such times may provide opportunities to sell surplus fish to local markets. This would also put co-operating communities at a competitive disadvantage with non co-operating communities in this context. The fact that trevally often display schooling behaviour (Thresher and Gunn, 1986) and may therefore be non-uniformly or ubiquitously distributed underscores this assertion.

*Spatial Closures*

According to the SPC (2011), establishing a fixed community-managed reserve where no fishing is allowed will be largely ineffective in protecting trevallies because they move from reef to reef and often travel long distances to particular spawning sites. This assessment concurs with Russ and Alcala (1998) who suggest that rates of recovery in protected areas are faster for site attached species. Kramer and Chapman (1999) further suggest that the greatest rates of recovery are expected when species have relatively small home ranges and are non-migratory.

Empirical studies have supported this theoretical framework. Jenkins et al. (2006) evaluated the effectiveness of a 12ha MPA in Madang Province, PNG, among different fish groups. After six years of protection, there was no significant change in the density of Carangids (or any other family of highly mobile predatory fish examined), despite a significant increase in overall fish density. For such species, the authors suggested that their high mobility would enable them to be removed from outside the protected area boundary. Tagging studies of *Caranx ignobilis* – an important species in NIP – have concluded that marine protected areas would need to be very large to offer protection to the species (Wetherbee et al., 2004; Meyer et at., 2007). While specific size thresholds were not offered, Myers et al. (2007) reported that, while many fish appeared to be attracted to 'core activity areas', excursions from such areas ranged up to 29km.

In a similar study on the bluefin trevally (another important study in NIP), Holland et al (1996) suggested that marine protected areas may an effective conservation tool owing to the species' high site fidelity and limited ranging behaviour for a highly mobile piscivourous species. Nonetheless, the area suggested for effective conservation (>5km of reef face) would still be beyond the likely capacity of community based and managed protected areas in New Ireland where no-take or tambu areas are typically smaller. Furthermore, the study focussed on sub-adult and adult fish. Therefore the habitat utilisation of juvenile fish was not considered and the area required for effective conservation of all life stages of this species may be considerable greater.

There are however studies suggesting that benefits to trevally populations may arise from no-take zones (Russ and Alcala 2003; 2004). The authors assessed biomass changes of four families of large predatory fish (Serranidae [groupers], Lutjanidae [snappers], Lethrinidae [emperors] and Carangidae [trevallies]) within two no-take marine reserve sites (38 and 23 ha) in the Philippines over a 17 year period. Grouped data indicated a continued and exponential increase in fish biomass over time. In this regard, Russ and Alcala (2004) suggested that 15 to 40 years of protection may be required for large predatory fish to attain "full recovery", owing to their general life histories. While these results appear encouraging in the current context, the pooled nature of the data does not enable biomass trajectories of Carangids to be assessed separately. Compared to the other Family groups, which generally display greater site attachment than Carangids, it is likely that the biomass trends observed in these two studies were not reflected in Carangid biomass changes owing to their relatively higher mobility.

*Temporal-Spatial Closures*

Numerous trevally species have been observed to form spawning aggregations that occur at predictable times and sites (i.e. bigeye trevally [Hamilton and Walter, 1999; Wilson et al., 2010] giant trevally, gold-spotted trevally [*Carangoides fulvoguttatus*] and black trevally [*Caranx lugubris*] [Hamilton and Walter, 1999]). Spawning aggregation sites commonly reported are the edges of coral reefs or near reef passages (Hamilton and Walter, 1999). Based on interviews with Solomon Island fishers, Hamilton and Walter (1999) suggest that spawning aggregations for most species occur around the full moon. An understanding of local spawning sites and times could enable temporal closures at such times and sites, such as known spawning sites at certain times of the lunar cycle. The potential effectiveness of such measures as a conservation tool for trevallies has been advocated by various authors (Wetherbee, 2004; Myer et al., 2007; SPC, 2011). However, different species are likely to have different spawning sites and times, so management activities that aim to manage a broad spectrum of Carangids may involve considerable time and effort in identifying temporal and spatial spawning characteristics. It is also worthy of note that some species do not appear to spawn in aggregations. For example, Hamilton and Walter (1999) concluded that the orange-spotted trevally (a species identified as important in New Ireland) did not form spawning aggregations.

Given the fairly long larval period (> 1 month) of most trevally species (SPC, 2011), it is likely that improvements in recruitment rate owing to temporal-spatial management measures will initially benefit down-current areas. However, unlike less mobile species, it is further likely that local improvements in recruitment will have a positive impact on fish populations on a regional geographic scale. This underscores the potential benefits associated with regional co-operation in any potential fisheries management efforts.

*Gear Restrictions*

According to the SPC (2011), gear restrictions that could be employed to manage community-scale trevally fisheries include a ban on overly efficient fishing methods such as gill nets and restrictions on gillnet mesh size. In a study on gear use in the PNG fishery, which included four sampling sites in NIP, McClanahan and Cinner (2008) reported that fishers typically used nets with mesh sizes between 2.4 and 4cm. Among ten species of Carangids caught during the study using three gear types (gill nets, lines and spearguns), five species were caught using gill nets, including the giant and bluefin trevallies. However, the size ranges of these fish were not reported. In another study on an artisanal multi-species tropical reef fishery, McClanahan and Mangi (2004) reported that fish caught using a mesh size of 6cm ranged between 14 and 20cm long. From this, it may be assumed that the mesh sizes used in PNG as reported by McClanahan and Cinner (2008) caught fish considerably smaller than this, underscoring potential fishery level benefits that may be accrued in addressing gear management.

In practical terms, assisting communities to replace small mesh net sizes with larger mesh nest would probably result in greater levels of acceptance and compliance than trying to implement a cessation on net fishing. However, given the large size of maturity of some key carangid species (i.e. 55-65 cm for giant trevally and 36.5 cm for bluefin trevally [Sudekum et al., 1991]), using a mesh to enable fish to reach maturity could be impractical for these species, particularly for use in a multi-species fishery. While mesh size restrictions may not be applicable for the larger species there are likely to be benefits for smaller trevally species and for other small to medium sized species. It is also likely that local knowledge of habitat use by different species could enable the deployment of nets at times and places that would reduce the capture of immature fish. In spite of the ways in which net design and deployment strategies may address conservation objectives, such measures are likely to have limited effectiveness unless complementary management measures are adopted at a geographic scale reflecting the ranges occupied by important fishery species.

## 3.2 MUD CRABS

### 3.2.1 Fisheries Information

The mangrove or mud crab, *Scylla* sp., is found in tropical and sub-tropical inshore areas from Africa to the Pacific Islands. While *Scylla serrata* appear to be the dominant species within the western Pacific region, other species including *S. paramamosain* exist in some areas, including PNG (Quinn and Kojis, 1987; WCS, 2013). Due to the apparent predominance of *S.serrata* in NIP (WCS, 2013), information presented in this section will apply to this species, unless mentioned otherwise.

Mud crabs are fast growing, particularly in warmer waters throughout their range (Quinn and Kojis, 1987). Male and female mud crabs can be easily distinguished, enabling sex-based management options. According to Hill et al., (1982) classification of size classes for *Scylla serrata are*; juveniles - 2-10 cm carapace width (CW); sub-adults 10 – 15 cm CW and adults are 15 cm CW and greater. However, other studies suggest smaller sizes at sexual maturation (e.g. Quinn and Kojis, 1987; Robertson and Kruger, 1994; Vu Ngok Ut et al, 1998). This variability appears to be dependent on *Scylla* species and location, with considerable variability in size at maturation also demonstrated for populations of the same species (Walton et al., 2006).

The importance of mud crabs to subsistence and artisanal fishers has been documented for various regions in PNG (Haines, 1979; Opnai, 1980; Quinn, 1984), including New Ireland (NFA, 2005a & 2005b). Regulations pertaining to mud crabs do not exist at the national level in PNG; however some locally managed areas, including some areas in NIP prescribe restrictions on size, the taking of berried females and closed fishing seasons.

### 3.2.2 Local Research

In 2004/05, the NFA conducted a 12-month survey of small scale fishing in northern New Ireland (NFA, 2005a). Focussing on Kavieng, the survey sought to better understand local fish landings through intercept surveys and market sales surveys through direct observations of seafood products offered for sale at Kavieng's markets. Some of the main findings are as follows:

From the landings survey, it was reported that only 1.2% of female mud crabs landed were berried, while the market survey did not report any berried individuals. However, the inconsistency in the manner in which reproductive condition data was collected for crustaceans was identified by the authors as a survey weakness. Thus, the proportion of berried females is likely to be higher than reported, an assertion supported by the results from the WCS mud crab survey (WCS, 2103), discussed below. There was an even sex ratio of males to females (51:49 respectively). Carapace widths of crabs ranged between 6.2 and 23.3cm, with a mean of 14.3cm. Approximately 55% of all crabs landed and for sale at the Kavieng market were sub-adults (<15cm) according to size classifications by Hill et al (1982). Around 11,000 mud crabs were for sale at the Kavieng main market over the 12 month survey period, representing almost 20% of all seafood items by numbers. Mud crabs were the seafood type contributing most to the daily incomes of sellers, with people selling mud crabs averaging a daily potential income of more than K49 (if all animals sold) compared with an average of K32 for people selling finfish (NFA, 2005a).

Most mud crabs were landed from November to May, with a peak in March. The seasonality of landings differs somewhat from the market survey where it was determined that the months with the greatest number of crabs for sale were February and July. This discrepancy between landings and sales suggests that, for the November to May period, a considerable proportion of harvested crabs were sold at places other than Kavieng markets. It is possible that during this period, greater tourist visitation to the area may result in a greater proportion of crabs sold to resorts and restaurants.

In 2012, WCS commenced a survey of mud crabs for sale at Kavieng markets from June 2012 to January 2013. Based on four months of data collection, an interim report suggests that mud crabs off northern New Ireland are dominated by *S. serratus*, with smaller numbers of *S. paramamosain* (WCS, 2013) (This assessment was consistent with Quinn and Kojis [1987] for the Labu estuary in PNG). While crabs for sale were recorded from 16 villages in the Tigak Islands, Tsoi Islands, Lavongai and off mainland New Ireland, more than 30% of the crabs were harvested from Kavulik in the Tsoi Islands. Of the 506 mud crabs identified in the survey, 377 were male and 129 were female. This discrepancy is curious given the equal gender ratios reported for the NFA (2005a) survey. One possible explanation is that the four month period for which results were reported may have coincided with the spawning season, in which case female crabs undergo considerable offshore migrations (discussed below) and were therefore not available to be caught within the fished mangrove areas at all times. This explanation is somewhat consistent with Quinn and Kojis (1987) who reported that from May to October, a skewed ratio towards male crabs may have coincided with offshore spawning migrations from the Labu estuary in PNG.

The WCS mud crab survey interim report also noted that 67% of the females for sale were berried. The report suggests that buyers preferred berried crabs and accordingly, harvesters may be preferentially targeting them. Clearly, there is a need to address this unsustainable practice. The study also indicated that 30% of crabs for sale were sub-adults (<15cm CW) according to the classification provided by Hill et al., (1982). Compared with the proportion of sub-adults (approx. 55%) reported for sale by the NFA (2005a), it appears that the time trend is a positive one. Nonetheless, it also suggests that more work in encouraging the harvest of only adult crabs may be required.

### 3.2.3 Ecology

The mud crab is found in muddy areas associated with mangroves and seagrass beds in the tidal mouths of rivers and sheltered bays (NFA, 2007). The crabs burrow in the mud and generally have a very limited home range (Hill, 1975; Hill et al 1982; Le Vay 2001). Studies suggest that, within mangrove systems, the distribution and abundance of mud crabs depends on their developmental stage, with a tendency for crabs to move further from shore at larger stages (Hill, 1975; Hill et al 1982; Le Vay 2001). In general, juveniles appear to frequent sheltered, shallow inter-tidal flats while adults prefer sub-tidal habitats. As adults, it also appears that there is habitat partitioning between males and females: adult males are commonly found in mangrove channels or in association with burrows located in mangrove forests while adult females are more commonly found on sub-tidal reef flats than in the mangrove forest proper (Hill, 1975; Perrine 1978; Nandi and Dev Roy, 1990). The agreement between these studies conducted in different areas suggests that these ecological characteristics may be ubiquitous across the range of the species.

Mangrove crabs eat small clams, worms, shrimps, barnacles, small fish, plant material and other crabs (SPC, 2011). They also eat smaller, injured or weak mangrove crabs. Juvenile mangrove crabs are eaten by wading birds and a wide range of fish, particularly as juveniles.

### 3.2.4 Reproduction and Life cycle

Mangrove crabs reach reproductive maturity in about 2 years and live for about 3 to 4 years when they can weigh up to 3.5 kg with a carapace width of up to 24 cm (SPC, 2011). The size at which mud crabs attain sexual maturity appears to be dependent on *Scylla* species and location, with considerable variation in size at maturity demonstrated for populations of the same species (Walton et al., 2006). A review of studies suggests that mud crabs attain sexual maturity at a smaller size at lower latitudes (Quinn and Kojis, 1987). For example, in South Africa (34$^{o}$S), *S. serrata* mature at 15cm CW (Hill et al, 1975) while in the Labu estuary in PNG (7$^{o}$S), 50% of female crabs were reported to be sexually mature at 10.5cm CW (Quinn and Kojis, 1987). The authors attributed these differences to temperature mediated impacts on growth. Given the mean annual water temperature at Kavieng is 29c (compared to 25c reported by Quinn and Kojis [1987]), logical extension may suggest that the age of sexual maturity of *S. serrata* will be even smaller in NIP than that reported for mainland PNG by Quinn and Kojis (1987). However, this is not supported by unpublished data from the WCS 2012/13 mud crab survey whereby the smallest reported berried crab was 13.3cm CW[1]. Therefore it is possible that the effects of temperature mediated growth on sexual maturity may trend downwards after a particular mean temperature threshold is reached. Another possibility is the existence of genetically isolated populations with differing biological characteristics owing to a lack of genetic connectivity between geographically isolated areas.

The seasonality of reproductive development and spawning behaviour also appears to vary widely between locations. Heasman (1980) suggests that the reproductive activity of *S. serrata* occurs year-round at low latitudes and seasonally at higher latitudes. However, at low latitudes, Heasman (1980, 1985) further suggests that peak spawning periods may coincide with periods of monsoonal rainfall, particularly in estuarine areas. It is thought that nutrient run-off from these rainfall events provides productive conditions that enhance larval survival. This assessment was supported by Quinn and Kojis (1987) on a study of *S. serrata* in PNG. They found that, although a percentage of the population is reproductive all year round, more crabs were reproductive from April-June and September-October, which coincided with seasonal rainfall patterns. Regarding the reproductive seasonality of mud crabs in NIP, preliminary analysis of a limited WCS dataset from seven months (June-January) of sampling shows no clear trend but apparent pulses at irregular times (late January, early October, early September and late July).

Copulation takes place directly after the female moults (Bomine 2008). During mating, the male crab transfers spermatophores to the underside of a soft-shelled (post-moult) female where the sperm is stored for many months. This period usually involves guarding of the female by the male crab (Bomine 2008). Females release over a million eggs which are fertilised by the stored spermatophore and stored externally on the underside of the tail. The female, now said to be 'berried' carries the eggs for about 12 days (SPC, 2011). During this period the colour of the eggs changes from bright orange to almost black as the young develop. Females move offshore (often many tens of kilometres) where the eggs are released and hatch to become zoea (larvae) about 1 mm long (Le Vay, 2001). Spawning migration distances appear to vary with location: it seems that female crabs migrate sufficiently to spawn in oceanic quality water with enough current to enable larvae to be effectively dispersed (Heasman, 1985; Hill, 1994). It is likely therefore, that spawning migrations of crabs in NIP will be relatively short owing to close access to oceanic waters and currents at many mangrove sites in the area.

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[1] Given a degree of natural variability in the expression of biological characteristics with an animal population, size at sexual maturity classifications are often based on the size at which 50% of the population attain sexual maturity. Therefore the discovery of a sexually mature crab of 13.3cm CW in New Ireland does not infer at this is the threshold size of sexual maturation for the population. Rather, it is likely to reflect the lower end of the natural variability of sexual maturity onset within the population. In the WCS (2013) survey, 8% of a sample of 83 berried females was below 15 cm CW – the size at which Hill et al (1982) provide as a general guide for sexual maturation for S. serrata. While further work and larger sample sizes will be required to conclusively determine a sexual maturity size threshold for New Ireland mud crabs,

Larvae are dispersed by currents and tides for about 3 weeks (SPC, 2011). It is thought that, after spawning, most females return to the same mangrove area from which they migrated (Heasman et al., 1985). Repeated spawning by individual females appears to be possible but has not been demonstrated conclusively (LeVay, 2001).

Late stage larvae (megalopa) settle on the sea floor and undergo a metamorphosis to become juveniles (about 4 mm wide) within 5 to 12 days (SPC, 2011). Less than one in every thousand megalopa survive to become a juvenile and less than one in every hundred juveniles survives to become an adult (SPC, 2011). It appears that recruitment success may be largely dependent upon the connectivity of mangrove areas within a region as the length of the larval stage would make local recruitment seem unlikely, especially in an area renowned for strong currents such as New Ireland.

### 3.2.5 Management Options

Community representatives at the February Small-Scale Fisheries Stakeholder Meeting identified nine potential options for mud crab management in NIP:

1. Size Limits (14-18cm CW)
2. Mangrove protection
3. Impose limits on fishing effort
4. Catch prohibition on moulting crabs
5. Closed seasons during moulting
6. The establishment of protected areas
7. Reduce damage to crab holes
8. Impose limits on catch numbers
9. Manage the harvest of crab food sources i.e. guma, king shells

The first three options) were identified as 'most preferred'. These options will be discussed in view of available literature on sustaining small-scale mud crab fisheries and dependent livelihoods.

*Harvest Restrictions*

Many fisheries management regulations have been applied to mangrove crabs, particularly in places where they are valuable in local markets. These measures include quotas or catch limits, restricting the number of traps used and the licensing of those selling crabs. However, these measures are generally not applicable in community-based fisheries (SPC, 2011). The reasons were not provided but it may be due to the unreasonable restrictions that it would place of the harvest of animals at times when they are required to be caught in greater numbers (i.e. for market days or for ceremonial purposes). Regardless, it is likely that any community based management action imposed will have poor compliance if measures are seen to be unreasonable or culturally inappropriate.

However, size limits (on carapace width) have been used successfully as a measure to sustain mud crab populations (Pillans et al., 2005; Ewel, 2008; Bomine, 2008) and such measures already exist in some locally managed areas in New Ireland. Size limits are also a preferred measure for small scale management as advocated by the SPC (2011) and by the Tutumarem Consultancy Services (1999) for NIP crab populations. Due to the existence of two *Scylla* species in New Ireland waters and considerable variation in size at sexual maturity between con-specific populations, minimum size limits may need to be site and species specific. As discussed above, the smallest size at sexual maturity onset in NIP appears to be around 13.3 cm CW, based on the identification of berried females at the Kavieng market. This size is however considerably greater than the SM50 of 10.5cm CW advocated by Quinn and Kojis (1987) for the Labu estuary in PNG and may be more consistent with the 15cm CW advocated by Hill et al. (1982). Therefore further work may be required to determine the local size at sexual maturity for both *Scylla* species.

Banning the harvesting of berried females or the harvest of females altogether are other options advocated by the SPC (2011) for small scale mud crab fisheries. Prohibiting the removal of female crabs has reportedly been an effective management tool for commercial crab fisheries in Queensland, Australia (Pillans et al., 2005). This was also a measure proposed by Tutumarem Consultancy Services (1999) for New Ireland mud crab fisheries. A harvest restriction on berried females – a commonly applied management measure in crab fisheries – would likely be easier to implement and have a greater level of compliance. This measure has also been incorporated into the management plans of some NIP communities (i.e. Ungakun and Kavulik). An evaluation of the effectiveness of these local measures would be prudent before deciding whether or not to implement this measure elsewhere. If sufficient information determined a low rate of success and a high rate of compliance, additional restrictions such as banning the harvest of all female crabs could be considered.

*Spatial Closures*

With regard to the suitability of no-take areas for mud crabs, the SPC (2011) suggest: "*Reserves (no-take areas) are unlikely to result in an increase in numbers of local populations of mangrove crabs as females move considerable distances off shore to spawn. This and the fact that the larval stages drift for several weeks suggests that juvenile crabs may settle in areas some distance from the reserve and local fishing areas*". While the potential for larvae to disperse over relatively large areas will likely limit the recruitment of locally spawned crabs, it has prompted some authors to advocate the establishment of protected area networks over larger areas (Tutumarem Consultancy Services, 1999; Pillans et al 2005; Ewel, 2008). This could sustain the connectivity of mud crab populations within a region. However, a better understanding of the nature of larval dispersal through oceanographic and other studies may enable potential sites to be identified more effectively. Also, the engagement and management co-operation between communities that are custodians of mangrove areas within a region would clearly be requisite in the establishment of protected area networks.

Regarding the first argument of the SPC (2011) against the use of protected areas, there is evidence to suggest that spawning migrations of female crabs from protected areas may not negate the effectiveness of no-take zones as suggested. Firstly, as mud crabs are generally not targeted by fishers outside mangrove areas (personal observations) they are unlikely to be caught during spawning migrations. Secondly, Heasman (1985) suggests that post spawning females return to pre-spawning locations. As such, it is doubtful that the lack of protection for spawning females during offshore migrations will undermine the effectiveness of protected area management to a large degree in this regard.

Some authors (e.g. Pillans et al., 2004; Bomine et al., 2008) advocate the implementation of protected areas for mud crabs due to their limited movements that still allow for some spillover into adjacent areas. The sensitivity of mud crabs to crowding supports this (Trino and Rodriguez, 2002). In view of the high growth rates of mud crabs, Bomine et al (2008) also suggest that a system of rotational harvesting of mangrove sites may be an effective way to ensure the harvest of larger individuals. However, the authors admit that such a system would be difficult to design, communicate, and enforce.

*Temporal Closures*

In some countries, catching mangrove crabs is prohibited during the reproductive period (SPC, 2011). Applying this measure relies on having regional knowledge of the timing of the spawning season. Based on the evidence relating to mud crab spawning periodicity, discussed above, it appears unlikely that spawning behaviour in NIP will be confined to discrete or predictable pulses. As such, temporal closures are likely to have limited benefit, despite being flagged as a management option in NIP by Tutumarem Consultancy Services (1999).

*Gear Restrictions*

The use of traps, as opposed to forked sticks, spears and digging is likely to be preferable in terms of releasing undersized crabs, minimising egg loss of berried females and limiting damage to mangrove areas. However, the impact of current harvesting methods on mangroves and crabs is yet unclear and may warrant investigation.

Traps are one of the best ways of catching mangrove crabs as they do not damage the caught crabs which can therefore be released if they are berried females or are too small (SPC, 2011). However, supplying mud crab traps to participating communities may represent a logistical hurdle and cost burden for the Project. Potentially however, traps could be produced locally from locally sourced materials.

*Culture of Wild Caught Crabs*

In some countries, the culture of mud crabs through the grow-out of collected juveniles has been used as a method of sustaining the livelihoods of mangrove dependent communities (Trino and Rodriquez, 2002). High growth rates and high market prices have stimulated much interest in crab farming throughout the Indo-Pacific region (SPC, 2005). Grow-out facilities range from fenced areas of mangrove to the construction of land-based grow-out ponds. These operations appear to have met with mixed success. Limiting factors include the density-dependent cannibalism of mud crabs which restricts stocking densities (Le Vay, 2001), and procuring a reliable supply of juvenile crabs and 'trash fish' for feed (SPC, 2005). The potential success of small scale mangrove-based crab farming using simple technologies would be greatly enhanced with a reliable supply of low cost food, such as waste products from a fish processing facility (E. Verheij pers. comm.). However, at present, no such supply exists in New Ireland. Regardless, it is likely that crab culturing as a species and livelihood conservation measure would be beyond the scope of this Project to pursue.

*Habitat Protection*

The loss of mangrove habitat represents a serious threat to mud crab populations (Le Vay, 2001). Mangrove protection has been flagged as a priority action for crab conservation in NIP by local stakeholders (WCS, 2014), Tutumarem Consultancy Services (1999) and the SPC (2011). Potential threats to the viability of mangrove systems as mud crab habitat include unsustainable harvesting practices (discussed above), the removal of mangroves for fuel and building materials and the effects of catchment activities. Some threats are being addressed through the MARSH project.

## 3.3 RABBITFISH

### 3.3.1 Fisheries Information

The family Siganidae includes 28 species, commonly called rabbitfish or spinefoots, in a single genus, *Siganus* (Woodland, 1990). Rabbitfish are widely distributed across the Indian and Pacific Oceans and occupy a wide range of latitudes. Some species are distributed across tropical and sub-tropical regions (Susilo et al., 2009). Rabbitfish occupy several habitats including coral reefs, seagrass beds and mangroves (Woodland, 1990). As adults, seagrass and mangrove dwelling species typically form schools while coral associated species generally live more solitary lives among the corals (R. Fox Pers. Comm.). While there is considerable size variation among rabbitfishes, they are typically, sort-lived (Grandcourt, 2002) fast growing, medium-sized fishes: most species reach between 25 and 35 cm (Woodland, 1990; SPC, 2011). The largest rabbitfish grows to about 60 cm (SPC, 2011). In many tropical regions, Siganids support important subsistence and artisanal fisheries (McClanahan and Mangi, 2004; Maina et al., 2013).

While rabbitfish appear to be iconic among New Irelanders, supporting an important subsistence and artisanal fishery, a rapid ecological assessment of northern New Ireland (Tigak Islands) and Manus Island (Hamilton et al., 2009) reported a greater abundance of rabbitfish in the latter region. As a proportion of total numbers of 'food fishes' (fishes that were deemed to be important to local fishers for personal consumption or sale) observed during transect swims, rabbitfish comprised 2.4% and 7.8% in waters off New Ireland and Manus Island, respectively. In terms of biomass, the relative values were 0.8% and 1.2%. In both provinces, the survey methodology, which focussed on coral reefs, may have underestimated the relative abundance and biomass of rabbitfish as some species primarily occupy seagrass beds or mangrove habitats (Woodland 1990; Fox, 2012). Furthermore, it is likely that the sampling sites at the Tigak Islands are not necessarily representative of the broader northern New Ireland area.

## Local Research

Overalll, Hamilton et al., (2009) reported eleven species of rabbitfish in their study, nine of which were observed at the Tigak Islands, New Ireland. Based on abundance classifications outlined in Hamilton et al., (2009), the most common species in New Ireland (Tigak Islands) were *Siganus coralinus, S. doliatus, S. puellus* and *S. vulpinis* (see Table 1). An NFA study of New Ireland fish market sales reported that 8.5% of all fish sold at the Kavieng fish markets were rabbitfish (NFA, 2005a). A survey of fish landings in New Ireland (NFA, 2005a) that ran concurrently with the NFA market survey reported that rabbitfish comprised approximately 5% of all fish harvested for market sales. Twelve rabbitfish species were recorded though only one species, the gold-lined rabbitfish (*Siganus lineatus*), was described in the report. This species accounted for 74% of all rabbitfish harvested, by number. As the gold-lined rabbitfish is one of the largest in the *Siganus* genus (growing to 60cm) the contribution of this species to total biomass of rabbitfish caught during the survey was likely to be considerably greater than 74%. The prominence of this species, as reported by the NFA (2005a) contrasts with the abundance classifications provided by Hamilton et al., (2009), where *S. lineatus* was reported as being 'moderately common' at their New Ireland sampling sites. The discrepancy with the reef sampling study by Hamilton et al., (2009) may be due to, in part, to the utilisation of mangrove, seagrass and coral habitats by *S. lineatus* (Fox, 2012). Other factors accounting for the discrepancy may include the targeting of rabbitfish in non-reef habitats by local fishers, distribution patchiness, fishing gear selectivity or temporal changes in species succession. It is also noteworthy that the majority of rabbitfish caught in New Ireland are used for subsistence consumption (WCS, 2014), widening the discrepancy between fish caught for sale (NFA, 2005a) and observations made by Hamilton et al., (2009).

A preliminary assessment of biodiversity data collected by the WCS at locally managed coral reefs in New Ireland between 2006 and 2010 suggests that all species of rabbitfish sighted were relatively uncommon. While further analysis of this data is required for a more conclusive assessment, the relatively low frequency of rabbitfish sightings is consistent with research on the density of reef-associated species (Cheal et al., 2012; Fox and Bellwood, 2013). It appears that, unlike seagrass/mangrove associated species that school and are found in locally high densities, coral reef associated species generally pair and have highly specialised feeding niches, limiting their potential densities around reef habitat (discussed in more detail below). At this stage therefore, it is likely that fishing activities targeting rabbitish would be based on fishing non-reef areas and/or spawning aggregations, while smaller numbers would be caught by netting and spearfishing on reefs during non species-specific fishing efforts.

Table 1. Abundance classifications for rabbitfish (Siganidae) species recorded during a rapid ecological assessment of New Ireland (NI) and Manus island (MI) (Hamilton et al., 2009). Classification keys are provided below the table.

| Common Name | Scientific Name | Abundance in NI | Abundance in MI |
|---|---|---|---|
| Forktail rabbitfish | *Siganus argenteus* | MC | MC |
| Coral rabbitfish | *Siganus corallinus* | C | C |
| Barred rabbitfish | *Siganus doliatus* | C | C |
| Dusky rabbitfish | *Siganus fuscescens* | NS | O |
| Gold-lined rabbitfish | *Siganus lineatus* | MC | MC |
| Masked rabbitfish | *Siganus puellus* | C | C |
| Fine-spotted rabbitfish | *Siganus punctatissimus* | MC | MC |
| Gold-spotted rabbitfish | *Siganus punctatus* | R | NS |
| Scribbled rabbitfish | *Siganus spinus* | R | NS |
| Foxface rabbitfish | *Siganus vulpinus* | C | C |
| Reticulated rabbitfish | *Siganus vermiculatus* | NS | R |

C (Common). The species was seen at the majority of sites in numbers that are relatively high in relation to other members of a particular family, especially if a large family was involved.

MC (Moderately Common). not necessarily seen on most dives, but may be relatively common if the correct habitat conditions are encountered.

O (Occasional). Infrequently sighted and usually in small numbers, but may be relatively common in a very limited habitat.

R (Rare). less than 10, often only one or two individuals seen on all dives.

MS (Not Sighted).

In terms of providing protein to New Ireland communities, rabbitfish represent a relatively efficient means of doing so (compared with the consumption of higher trophic order fish) due to their herbivory and relatively fast growth rate. These life history traits coupled with a short life span and a high population turnover rate suggest that Siganids are relatively resilient to exploitation (Jennings et al, 1999; Grandcourt, 2002). However, herbivorous coral reef fish are important for reef health and resilience and overexploitation of this resource may results in ecosystem shifts from coral to macroalgal dominance (Mumby et al 2006; Fox and Bellwood, 2007, 2008; Cheal et al, 2010; Lorkanze et al, 2010). Nonetheless, due to the high diversity of feeding niches and ecosystem roles among rabbitfish, ecological consequences of exploitation are likely to be different for different species (Fox and Bellwood, 2013; Hoey et al., 2013) and conservation efforts may therefore need to be species or guild specific. Input provided at the stakeholder's meeting for small-scale fisheries in February 2014 suggested that rabbitfish populations in New Ireland were declining, though species-specific information was not provided. However, a study examining spawning aggregations for the New Ireland and Manus Island regions suggested that populations of the most commonly caught species, *S. lineatus*, were stable in New Ireland while populations of *S. canaliculatus* and *S. vermiculatus* were decreasing at Manus Island (Hamilton et al., 2004). While these assessments are ten years old, the results underscore the need to undertake population assessments of important species before undertaking conservation measures.

### 3.3.2 Ecology

Compared to other reef-dwelling herbivores such as parrotfish and surgeonfish, the ecology of rabbitfish has received little attention from researchers (Fox, 2012). What is known suggests a high degree of niche specialisation with regard to diet, feeding behaviour, habitat use and ecosystem functioning (Fox, 2012). Adult rabbitfish utilise a range of habitats including estuaries, mangroves, seagrass beds, lagoons and shallow coral reef flats and are predominantly diurnal feeders (SPC, 2011), though some species such as *S. lineatus* are reportedly facultative nocturnal feeders (Fox, 2012).

Among Siganids, it appears that habitat use, social organisation and diet are related to body shape (Woodland, 1990; R. Fox, Pers. Comm.). Regarding habitat use, Woodland (1990) suggests that Siganids can be divided into two distinct groups based on body shape: one group comprising the deep-bodied, reef-associated species, and the second comprising fusiform-shaped species that are more typically associated with seagrass and other non-reef habitats. According to more recent research however, Woodland's classification may not be a strict one (R. Fox, Pers. Comm). For example, the deep bodied species *S. javus* and *S. vermiculatus* prefer brackish estuarine waters, unlike their deep-bodied reef associated counterparts. Such polarisation in habitat preference and associated behaviours has also been observed between conspecific populations: Fox and Belwood (2011) determined that separate populations of adult *S.lineatus* on the Great Barrier Reef may occupy both mangrove and coral reef habitats. In that study, mangrove populations of *S. lineatus* were observed feeding during the day over sandy bottom and remained stationary at night in rest holes while coral reef dwelling fish fed during the night and rested at the edge of coral bommies during the day.

Along with surgeonfishes, rabbitfish have typically been viewed as occupying the feeding niches of "algal browsers" (Cheal et al., 2010) or "algal croppers" (Choat et al., 2002). However, recent research has identified a greater degree of niche specialisation among rabbitfish, which also appears to be related to morphology (Fox and Bellwood, 2013; Hoey et al., 2013). While fusiform non-reef species are typically regarded as macroalgal browsers (R. Fox Pers. Comm.), a recent study by Hoey et al. (2013) which examined the feeding roles of 11 coral-associated species of rabbitfish (eight of which have been recorded in New Ireland by Hamilton et al [2009]), identified four distinct feeding groups: browsers of brown macroalgae (*S. canaliculatus, S. javus*), croppers of red and green macroalgae (*S. argenteus, S. corallinus, S. doliatus, S. spinus*) mixed feeders of algae, cyanobacteria and detritus (*S. lineatus, S. punctatissimus, S. punctatus, S. vulpinus*) and sponge feeders (*S. puellus*). According to Fox (2012), herbivorous rabbitfish display a high degree of feeding specialisation compared with other reef-dwelling herbivores (i.e. parrotfish and surgeonfish), typified by feeding on cryptic crevice-dwelling algal communities; a feeding behaviour enabled by their snout morphology. The feeding habits of herbivorous rabbitfish are believed to be important in keeping coral free of suffocating plant growth (Mumby et al., 2006; Lorkanze et al., 2010; Fox, 2012). Indeed, low densities of rabbitfishes (in particular *S. doliatus*) have been associated with a shift to macroalgal dominance on reefs in Australia, while nearby reefs with higher densities of rabbitfishes remained coral dominated (Cheal et al. 2010). Despite the specialised vegetarian diet of most rabbitfish, some species such as S. *magnificus* (Allen, 2010) and *S. argenteus* (McClanahan and Cinner, 2008) appear to be opportunistically carnivorous as they have been caught on baited hooks. The capture of rabbitfish using angling methods was also reported at the February small-scale fisheries management meeting.

Morphology and habitat use also appear to be related to social organisation of adult fish (R. Fox, Pers. Comm.). In general, non-reef fusiform fish tend to form schools while deep-bodied reef-associated fish tend to form pairs (Hoey et al., 2013). However, *S. lineatus* and *S. vermiculatus* appear to be two exceptions (R. Fox Pers. Comm.). On reefs, *S. lineatus* often move in schools of 3-7 fish, and sometimes many more (R. Fox Pers. Comm.).

As reef-associated rabbitfish species occupy specialised ecological niches, their distribution and abundance is closely linked to food availability. For example, studies have shown that the distribution of browsing rabbitfishes is closely related to the distribution of brown algae (Wismer et al., 2009; Hoey and Bellwood, 2010). Reef dwelling rabbitfish are also generally more abundant on inshore reefs than offshore reefs (Hoey et al., 2013). As densities of other major herbivorous fishes such as parrotfish and surgeonfish are typically low on inshore reefs (Cheal et al., 2012), the role that rabbitfish play in preventing macroalgal expansion on coral reefs is likely to be important (Hoey et al., 2013). Siganids are also important in coral reef food webs as they are eaten by a large number of reef fish (SPC, 2011).

The range in which a species occupies has pertinent implications for many fisheries conservation and management measures. Recent research on *S.lineatus* and *S. doliatus* – two species of deep bodied rabbitfish common in New Ireland – suggests that rabbitfish may have strong site dependency and limited home ranges (Fox, 2011). The respective average recorded ranges for *S.lineatus* and *S. doliatus* were 3.2ha and 180m stretch of reef. However, these ranges are not likely to include distances travelled to spawning sites.

### 3.3.3 Reproduction and Life Cycle

Being fast growing and short-lived, rabbitfish attain sexual maturity at a relatively young age (Woodland, 1990). Different species may become sexually mature within 1 or 2 years (at a length of about 15 cm) and reach lengths of over 40 cm (SPC, 2011). Rabbitfish form large spawning aggregations which often occur on outer reef slopes or crests and channels through the reef (Johannes, 1978; Hamilton et al., 2004). Some authors have termed rabbitfish 'transient spawners' owing to their tendency to travel relatively long distances to spawning aggregation sites (Domeier and Colin, 1997; Sadovy and Domeier, 2005; Sadovy de Mitcheson et al., 2008).

The timing of reproductive development and spawning varies with latitude. This has been demonstrated both across and within *Siganus* species (Takemura et al., 2004; Susilo et al., 2009). At higher latitudes, reproductive activity appears to be linked to seasonal fluctuations in photoperiod and water temperature (Rahman et al., 2000). However, at lower latitudes, gonadal development may occur during the transition period between dry and rainy seasons, suggesting that periodic changes in aquatic environments related to monsoons act as a cue for reproductive activity (Takemura et al., 2004; Susilo et al., 2009). The duration of these peak periods may last for some months (Susilo et al., 2009). From a review of literature on the reproductive biology of rabbitfish (Takemura, 2004), it appears that most rabbitfish species at low latitudes exhibit one protracted spawning period per year while some species (i.e. *S. oramin* [Soh and Lam, 1973]) have a second minor reproductive period. Furthermore, individual rabbitfish may spawn numerous times during a protracted spawning season (Takemura et al., 2004).Of relevance to the current Project, Hamilton et al. (2004) determined that in New Ireland, *S. lineatus* formed monthly spawning aggregations all year round. The same study also reported year round spawning behaviour for *S. vermiculatus* and *S. canaliculatus* in waters off Manus Island. These results suggest that all Siganids in the Bismark Sea region may be year-round aggregative spawners which is likely due to environmental factors associated with the equatorial location.

While reproductive development across the *Siganus* geographic range appears to be significantly influenced by latitude, numerous studies suggest that the influence of lunar cycles in stimulating advanced reproductive development and spawning activity may be somewhat ubiquitous among rabbitfishes (e.g. Hoque et al., 1999; Harahap et al., 2001; Rahman et al., 2001, 2003; Takemura et al., 2004; Susilo et al., 2009; Soliman et al., 2009). Spawning is generally synchronous and often occurs around the period of the new moon (Takemura, 2004; Susilo et al., 2009; SPC, 2001; Robinson et al., 2011). However, some species such as *S. guttatus* (Rahman et al., 2000) and *S. vermiculatus* (Popper et al., 1976) spawn at around the first quarter of the moon. For *S. lineatus* however, a New Ireland study reported that the species spawned for two or three days before the full moon in aggregations of between 200 and 1000 fish (Hamilton et al., 2004). This finding contrasts with a Palau based study which reported spawning behaviour of *S. lineatus* to occur between days 5 and 13 of the lunar month (Johannes, 1978). While these reports demonstrate a degree of plasticity regarding reproductive strategies, the timing of spawning aggregations in New Ireland is of significance to the current Project, particularly in view of the importance of *S. lineatus* to local fishers (NFA, 2005a).

During spawning, females typically release 0.5 - 2 million eggs (SPC, 2011). The fertilised eggs are sticky and demersal and adhere to the sea floor before hatching (Gundermann et al., 183). The laying of demersal eggs is somewhat unique among aggregation spawners and among fish that provide no parental care of offspring (Domier and Colin, 1997). The larval stage typically lasts between 1 to 2 months (SPC, 2011); however, it may be as short as 17 days for *S. spinus*

(Soliman et al., 2010) and 15-16 days for hatchery produced *S. guttatus* and *S. canaliculatus* (Juario et al., 1985; Hara et al., 1986).

It is estimated that less than one in every thousand larvae survives to become a juvenile (SPC, 2011). Based on observations of *S. argentus, C. Canaliculatus and C. Spinus,* pelagic juveniles appear to settle in coral reef areas during the flood tide after the new moon (Kishimoto, 1984; Tawata 1988; Soliman et al., 2010). It is thought that settlement at or around the new moon has the advantage of maximum evasion from predators because of the associated darkness as well as the strongest current drift shoreward due to the maximum difference between high and low waters during this lunar phase (Soliman and Yamaoka, 2010).

Nursery areas for juvenile fish include mangroves, seagrass beds and coral reefs where they often form dense schools. In general, the habitat occupied by juveniles is the same as the habitat occupied as adults (R. Fox. Pers. Comm.). Fusiform species tend to recruit in large schools over reef flats and seagrass beds while deep-bodied coralophilic species tend to recruit on coral reefs as individuals and live within branching corals until they reach about 10cm and then form pairs (R. Fox. Pers. Comm.). However, some species appear to undergo ontogenetic habitat shifts between juvenile and adult stages (Duray, 1998). The ability to utilise a wide range of habitats is probably linked to the resilience of some studied species to extreme fluctuations in temperature, salinity and dissolved oxygen (Gunderman et al., 1983). It is estimated that less than one in every hundred juvenile rabbitfish survive to become adults (SPC, 2011).

### 3.3.4 Management Measures and Options

The high number of species in New Ireland coupled with the high diversity of ecological niches and life cycle strategies poses logistical challenges for the management of rabbitfish. Such challenges may necessitate a focus on individual species or guilds for effective management. Where applicable, gaps in knowledge required to develop management strategies will be identified.

Community representatives at the February Small-Scale Fisheries Stakeholder Meeting identified five potential options for rabbitfish management in NIP:

1. Impose minimum net mesh sizes (i.e. >3 inches)
2. Conduct biological/ecological research to guide management efforts
3. Influence consumer demand on size and species with conservation benefits
4. Restrict/ prohibit the capture of females during spawning period
5. Impose limits on catch numbers

The first three options were identified as 'most preferred'. All options will be discussed in view of available literature and other management alternatives to sustain small-scale rabbitfish fisheries and dependent livelihoods in New Ireland.

*Harvest Restrictions*

The selling of rabbitfish at Kavieng markets as small as 7cm (NFA 2005a) suggests that the harvesting of immature fish needs addressing. Minimum size limits have been applied in some Pacific Island countries at a national level (SPC, 2011) but this may not be feasible in the current context. Impediments to implementing community based minimum size restrictions include:

The large number of *Siganus* species (approximately 12) harvested in New Ireland waters. Given the wide size range of these species, it is likely that size at sexual maturity will also be variable between species. Even if these sizes were known, species-specific minimum size limits would be impractical and burdensome to implement and enforce. However, given that *S. lineatus* appears to comprise the bulk of catches, size restrictions could potentially be applied to this species only.

Anecdotal information suggests that one of the main gear types used to target rabbishfish in New Ireland – gill nets – are generally of a mesh size that capture immature rabbitfish. Due to potentially high post-release mortality, difficulties in handling live rabbitfish (owing to their poisonous spine) and the cultural unfamiliarity of releasing fish, management measures requiring fishers to release undersized fish from nets would likely not be tenable. Therefore, the imposition of a minimum size limit whist retaining small mesh gillnets is not likely to be an effective option. The conversion to larger gill net mesh sizes is discussed below under 'Gear Restrictions'.

If the movement range of rabbitfish above current exploitable size (the minimum sale size was reported as 7cm in NFA [2005a]) is greater than the range managed by a co-operating community, adhering to size limits (which will be greater than current exploitable size) will put that community at a competitive disadvantage relative to adjacent communities. Despite these obstacles, the implementation of minimum size limits for *Siganus* sp was flagged as a preferred management option at the Packard fisheries project Stakeholders Meeting. Also flagged was the implementation of minimum sizes for sale at local markets, though how this could be achieved is uncertain given the lack of regulatory mechanisms at this level. The implementation of catch limits is also possible. However, the SPC (2011) suggest that such measures are usually inappropriate in community fisheries unless the catch is to be sold.

*Effort Restrictions*

Some fishing communities have banned night fishing with spears because the fish are vulnerable when sleeping in seagrass (SPC, 2011). However, prohibiting spear fishing should not be considered given that spearing is a highly targeted form of fishing, which generally catches fish of the desired species and size, particularly among experienced fishers (McClanahan and Mangi, 2004). While proponents of night spearing bans claim that the practice is "too effective", it can be reasonably argued that making fishing more difficult should not be a desirable outcome of management efforts. This argument, off course, assumes that night spearing is continued at a sustainable level but the more preferred management options detailed below (spawning closures and changes to net mesh sizes) should be more effective in addressing sustainability concerns.

*Spatial Closures*

The establishment of community-managed areas where no fishing is permitted may allow fish numbers to increase but will not protect the fish during their spawning migrations and at their aggregation sites unless other measures are taken (SPC, 2011). It is uncertain whether the size of protected areas under the tenure of individual communities would be large enough to span the range occupied by rabbitfish at juvenile and adult stages, particularly in view of ontogenetic shifts in habitat occupation by some species. Even as adults, some species such as *S. lineatus* have been reported to occupy both seagrass and coral habitats (Fox, 2012), potentially limiting the effectiveness of small protected areas. However, the small home ranges and high site fidelity reported for adult *S. doliatus* (Fox et al., 2009) may indicate potential effectiveness of protected areas for this species and others with restricted home ranges.

Currently, there are knowledge gaps that would need to be addressed if protected areas are considered as a management alternative. Perhaps most prominently, more information about the utility, population status and site fidelity of species important to New Ireland communities is required. Due to the predominance of *S.lineatus* for sale at the Kavieng market (NFA, 2005a), any protected area would need to include key habitat for this species, which may need to encompass both seagrass and coral areas (Fox, 2012). With regard to species that are wholly or predominantly coral associated (i.e. *S. doliatus, S. corralinus, S. puellus, S. punctatus, S. Punctatissimus* and *S. vulpinus*), they are unlikely to occur in sufficient densities to constitute an important fishery owing to their highly specialised ecological niches and non-schooling behaviour. This assessment is supported by their low count frequency during rapid ecological assessments of Tambu (and control) reefs by the WCS in New Ireland.

*Temporal-Spatial Closures*

Given the tendency for spawning aggregations to be targeted by fishers, the protection of known spawning sites on a permanent or temporary basis has been flagged as a potentially effective management option for rabbitfish (Samoileys et al., 2006; Agembe, 2012; Maina, 2012; Soliman et al., 2009). The tendency for all studied *Siganus* species to form spawning aggregations according to predictable times of the year and lunar cycles underscores the potential for conservation outcomes based on spawning closures. Indeed, the targeting of spawning rabbitfish was identified as an issue of concern by the NFA (2007).

Unlike many studies worldwide which indicate spawning of siganids during defined times of the year, Hamilton et al. (2004) reported that *S. canaliculatus, S. vermiculatus* and *S. lineatus* spawned monthly on a year-round basis in the Bismarck Sea region. This suggests that all species of rabbitfish may have similar reproductive strategies within the region. However, the same study reported that *S. canaliculatus, S. vermiculatus* formed aggregations in the days following the new moon while *S. lineatus* formed aggregations in the days before the full moon.

Clearly, protecting fish during spawning will require a detailed knowledge of species-specific spawning sites and times. Such information can be informed through local knowledge provided by fishing communities. Once known, it may be possible to implement temporal closures at identified spawning sites which may involve several short closures at monthly intervals. Given the number of siganids reported to occur in the New Ireland region, spawning closures would likely need to be confined to the most important species. While S. *lineatus* appears to comprise the bulk of catches (NFA, 2005a), Hamilton et al. (2004) suggest that local populations of this species are stable with no appreciable population decline despite being targeted using spearguns during aggregations for generations. This would suggest that conservation measures may not be required; however, given the time at which the study was conducted, more recent declines may be apparent. It is possible that the use of spearguns to target aggregating fish may have been replaced with more efficient gears such as gillnets. This may need to be investigated further before planning spawning closures for this species.

Despite the overall support for spawning aggregation closures by the above researchers, its use as a conservation measure was not supported in a study on the rabbitfish (mainly *S. sutor*) trap fishery in the Seychelles (Robinson et al, 2011). Reasons specific to the Seychelles fishery included the overall small contribution (15%) of spawning aggregation fishing to total annual catches, marketing restrictions which constrained the disposal of large catches, the existence of unfished spawning areas and the supposition that aggregation closures may transfer fishing effort to juvenile fish. It would be prudent to investigate whether these issues are also relevant in New Ireland before planning spawning closures. Robinson et al. (2011) also suggested that, compared to many aggregative spawning tropical fish species, siganids are resilient to overexploitation due to their short life span, rapid growth rate and a high population turnover rate (Grandcourt, 2002).

Robinson et al. (2011) also discussed the implications of managing aggregation sites of transient spawning rabbitfish (predominantly *S. sutor*) for local fisheries. If long spawning migrations are apparent for important fishery species in New Ireland (e.g. *S. lineatus*), planning and management challenges should arise. It is probable that spawning sites for important fishery species will not be located in waters within the jurisdiction of participating communities. Based on knowledge provided by local fishing communities, Hamilton et al (2004) identified five aggregation sites for *S. lineatus,* all located within 5 square kilometres within the New Ireland region encompassing the Tigak Islands, Tsoilik Islands and Djaul Island[2]. Given the extensive study methodology which surveyed 14 communities in the region, it is likely that this species may undergo considerable migrations from surrounding areas to access these sites, with important implications for their protection.

If spawning sites are identified within participating communities' waters, there are likely to be management challenges as fishery benefits arising from site protection are likely to benefit neighbouring and/or regional communities, not just participating communities. Determining how localised benefits may be arising from conservation measures may require knowledge of the distance of larval dispersal and whether spawning fish return to home sites. Without knowing these things, there may be problems gaining community acceptance of spawning season closures as participating communities will be forgoing catch opportunities for the benefit of neighbouring or regional communities. This situation further underscores the opportunities that may become available under co-operative management arrangements that aim to 'even out' initial catch reductions experienced by individual communities through a system of conservation trade-offs.

*Gear Restrictions*

In some areas the banning of gill nets by fishing communities has protected against the overharvesting of rabbitfish, particularly during spawning migrations and aggregations (SPC, 2011). Studies have shown that rabbitfish populations respond positively and rapidly to the removal small mesh sized nets (Hamilton et al., 2004; McClanahan et al., 2008; McClanahan and Hicks, 2011). In the latter study, McClanahan and Hicks (2011) reported a mean length increase of 6.8cm for *Siganus sutor* in ten years following the removal of small mesh seine nets from a Kenyan fishery, the greatest recovery of 15 species examined.

However, the permanent banning of gill net fishing may be viewed as unreasonable as adult rabbitfish are reportedly difficult to catch by angling methods. An alternative is to restrict the use of small-mesh gill nets by imposing a minimum mesh-size. This could reduce the capture of juvenile fish, a problem identified in various Siganid fisheries (Soliman et al., 2009; Robinson et al., 2011; Agembe, 2012). A yearlong ban on the use of nets with mesh smaller than 75mm (together with seine nets and spearguns) resulted in a marked increase in the abundance and size of siganids in a Manus Island community (Hamilton et al., 2004). While these changes were based on fisher perception and not quantitative survey methods, rapid increases in fishery health under more restrictive fishing regimes would be enabled by the biological characteristics of rabbitfish such as fast growth rate, short lived and young age at sexual maturity (Grandcourt ,2002).

Different species of rabbitfish are likely to have different sizes at sexual maturity, which will be an important consideration in net mesh conversion. However, the local predominance of one of the largest rabbitfish species, *S.lineatus* may serve to simplify this issue. Conversely however, a net size appropriate for this species may preclude the capture of smaller species of rabbitfish, with negative conservation and livelihood implications. However, it is likely that gillnetting efforts in New Ireland focus on seagrass areas in which case *S. lineatus, S. argenteus* and *S. fuscescens* are the main species caught. Further work examining habitat and resource partitioning between species may enable nets (and other gears) to be deployed more selectively allowing the effective targeting of individual species. Providing communities with larger mesh gill nets may impose logistical difficulties for the Project but could be considered nonetheless (McClanahan and Cinner, 2008). Issues surrounding efforts to determine an optimal mesh size for a fishery are discussed in MacLennan (1992)

The SPC recommends that the combination of periodic fishing closures of spawning aggregations, restricting net mesh-sizes and the protection of local seagrass beds may be the most effective actions a community can take to address the sustainability of rabbitfish fisheries.

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[2] The locations of these sites were not provided to avoid the intensification of fishing efforts

## 3.4 TROCHUS

### 3.4.1 Fisheries Information

the New Ireland region is *Tectus niloticus* (two other species exist locally but are of no commercial value). *T. niloticus* is a large species (up to 150 mm across the shell base) which has an off-white shell with oblique reddish stripes and an interior layer of thick pearly shell. This species is harvested for its flesh and particularly for its shell which is used to make mother of pearl buttons. In New Ireland Province, almost all trochus shell sales are for export markets, with very few sold at Kavieng markets (NFA, 2005a).

Available information suggests that the trochus fishery in the region is over-exploited. According to the SPC (2011) and the Coral Triangle Initiative (CTI, year?), the minimum recommended population threshold before opening a sustainable fishery is 500 to 600 trochus per hectare. At that density, the CTI suggests that annual harvests should not exceed 30% of the adult population. Reef surveys conducted in NIP between 1988 and 1990 estimated that trochus densities ranged from 34 trochus/ha in Djaul to 135 trochus/ha in Mussau (Tenakanai, 1990). Such densities suggest that, at the time, regional trochus fisheries were facing serious sustainability challenges. Currently, efforts are being made to determine whether more recent data for the New Ireland region is available.

The shallow distribution and ease of capture, due to a lack of mobility, mean that *Trochus* can be easily over-harvested. It is likely that the ability to store *Trochus* shells for later sale (i.e. harvested animals are not required to be caught fresh) has also contributed to the apparent high level of fishing pressure. Fortunately however, *Trochus* populations respond well to temporary closures (such as *Tambu* closures) in the Melanesian region (Foale, 1998). Furthermore, trochus often display cryptic behaviour by hiding in rock and coral crevices, and thus can avoid detection by divers. This has been suggested as a reason for why trochus populations have not experienced the same degree of stock collapse as other high value sessile invertebrates such as green snail and sea cucumbers (Foale, 2006, 2008), in addition to protections afforded by size limits imposed by the National Fisheries Authority (discussed below).

### 3.4.2 Ecology

Trochus are diurnal herbivorous feeders, grazing on algal films on coral and rocks (Nash, 1993). Juvenile trochus settle in shallow areas among the boulders and rubble on intertidal reef flats. Adult trochus tend to aggregate on outer reef flats and reef crests with abundant stony corals and areas of turf algae and may be found on reef slopes down to depths of about 15 m (Nash, 1993). However, most adults are found within a depth of eight metres, making them easy to collect for divers (Foale, 1998). Given the limited mobility of trochus, Smith (1987) suggests that the most productive trochus habitats are those whereby preferred juvenile and adult habitats are in close proximity. Trochus also require adequate water circulation and tend to be more abundant on reefs with some wave action (Foale and Day, 1997). Natural predators of trochus include sharks, stingrays, bailershells and crabs (Kinch, 2002).

### 3.4.3 National Regulations

Due to sustainability challenges experienced in this important commercial fishery, the NFA has imposed a slot limit (80 – 120mm basal width) for *Trochus* collected for export. The minimum size limit of 80mm ensures that individuals are sexually mature for about a year before they enter the fishery. The maximum size limits of 120mm is justified on the grounds that larger females produce a greater number of eggs and the shells of older individuals are less valuable due to worm infestation.

All exporters are required to hold a licence and there are limits on the number of licences allocated within each province. Furthermore, the NFA also prohibits the harvesting of trochus at night using underwater lights and using scuba and hookah gear.

### 3.4.4 Reproduction and Life Cycle

Trochus have separate sexes and are able to reproduce at about 2 years of age when they have a base diameter of between 55 to 70 mm (SPC, 2011). They can live for up to 15 years. Spawning occurs throughout the year in warmer areas and during the warmer months in cooler areas within their range (SPC, 2011). They may form loose spawning aggregations at night within 1 or 2 days of either a full or new moon (Kinch, 2002). It is believed that individual trochus spawn once or twice per year.

Trochus are broadcast spawners and females usually release eggs in response to the presence of sperm in the water. This mode of fertilisation means that when stock densities decline below a certain threshold, the increasing average distance between spawning individuals, and consequent dilution of gametes, results in a decrease in fertilization success – termed the 'Allee effect'(Levitan, 1995). The fertilised eggs hatch as veliger (larvae) that drift with currents in the sea for 3-4 days before settling on a rocky surface where they undergo metamorphosis into a benthic *Trochus* juvenile (Heslinga, 1981). During this time, larval-juvenile metamorphosis, and therefore recruitment settlement may occur from hundreds of metres to tens of kilometres from the spawning site, depending on current regimes, bottom topography and a number of other factors (Foale and Menele, 2004). The SPC (2011) suggests that the juvenile recruitment rate is less than one in a thousand while less than one in every hundred juveniles is estimated to survive till sexual maturation.

### 3.4.5 Management Measures and Options

Community representatives at the February Small-Scale Fisheries Stakeholder Meeting identified six potential options for shellfish management in NIP:

1. Establish Tambu areas
2. Conduct biological/ecological research including species life cycles and the identification of important habitats/ life stages
3. Public/community awareness of existing regulations and species' status and threats
4. Encourage adherence to existing size limits
5. Restocking of depleted stocks through farming
6. Regulation of harvesting limits

The first three options were identified as 'most preferred'. All options will be discussed in view of available literature and other management alternatives to sustain small-scale shellfish fisheries and dependent livelihoods in New Ireland.

Give the short duration of larval dispersal, trochus populations are very susceptible to recruitment overfishing at the scale of individual reefs (Foale and Day, 1997). While this means that localised declines cannot usually be addressed through region-wide processes, it also means that management measures that effectively address sustainability challenges can produce tangible local benefits (Nash, 1993). Regarding community based management of trochus in the Solomon Islands, Foale (2006, 2008) stressed the need for management efforts to be complemented by extensive education programs, especially as they relate to larval dispersal and the need to retain sufficient numbers of adult animals to prevent recruitment failure. Clearly, this is also applicable for community based management in PNG.

*Harvest Restrictions*

A nationally imposed slot limit of between 80 and 120mm was applied in PNG in 2002. However, this limit does not apply to subsistence fisheries suggesting that there may be scope to encourage size limits for locally consumed trochus. Despite this, it appears that most catches are destined for export markets in which case the size limits would be largely applicable, and the onus of compliance would also apply to the exporter. However, the sustainability challenges facing the fishery infer that this measure, alone, is insufficient to address the balance between population densities and minimum threshold sustainability densities advocated by the SPC and CTI. Foale and Day (1997) suggest that increasing the minimum size limit to 90mm would likely have a significant impact on increased egg production and yields. This was also flagged as a potential management measure for the Torres Strait *Trochus* fishery (Murphy et al., 2010).

Foale (2008) suggests that the best managed trochus fishery in the Pacific region is that of Auitutki in the Cook Islands which is underpinned by a simple quota system subject to regular stock assessments involving members of the local community. However, Foale (2008) is sceptical about the likely success of a similar system in Melanesian countries and anticipates a low level of compliance given the high levels of social and political fragmentation and low levels of governmental resources. Nonetheless, the SPC (2011) suggest that the establishment of community quotas (for an area or region) could be implemented as a community-based measure which could also involve community members in conducting pre-season stock assessments. In this context, the SPC (2011) recommend that the total annual harvest of trochus should not exceed 30-40% of legal sized animals.

*Gear Restrictions*

The NFA prohibits the harvesting of trochus using scuba and hookah gear. Opening the fishery to SCUBA and hookah gear is likely to erode the sustainability benefits afforded by the animals' cryptic behaviour and any efforts to do so should be resisted.

*Spatial and/or Temporal Closures*

Temporary closures of depleted areas have been suggested by various authors (Foale, 2008; Murphy et al., 2010; SPC, 2011). Any closure would have to be for a long period to allow time for stocks to recover and for adults to breed. Customary closures of between 1 week and 6 months per year, in combination with minimum size restrictions, prevented the decline in trochus stocks in Indonesia (Evans et al, 1997). To be effective in rebuilding trochus stocks, Murphy et al (2010) suggest a closure period of 3-5 years. The same authors also flag the possibility of a temporary closed season in 'open' fisheries during the spawning months, though it is not clear whether a temporally defined spawning season exists in New Ireland.

Foale (2008) is generally critical of the effectiveness of temporary *tambu* closures for sessile commodity fisheries in the Melanesian region. This is because when the closed area is opened to fishing, fishing effort can often be very intense and unrestrained – people usually harvest every last individual that they can find. However, he suggests that serial closures as a form of adaptive management can be applied with relative success for *Trochus* fisheries owing to their cryptic behaviour which prevents the detection and capture of some animals:

"In the case of trochus, it appears that a certain proportion of the population, perhaps up to a third, is hidden deep in reef crevices and out of reach of divers at any one time. Indirect evidence for this behaviour is provided by the observation that trochus populations tend to increase noticeably just after the full moon in summer months, when many animals apparently leave their hiding places and move to relatively exposed positions on the reef to spawn. A serial closure system means that those individuals that evade capture during a harvest (assuming all harvests are not timed to coincide with spawning) will then enjoy protection during the subsequent prohibition, and this may guarantee a level of population replacement sufficient to prevent stock collapse."

Permanent closed areas are also a management option. The expectation is that young trochus will be produced and these will settle in nearby areas. Clearly however, protected reefs will need to be within the range of larval settlement of neighbouring reefs. Foale (1998) suggests that *Trochus* larvae, which remain planktonic for 3-4 days, can drift up to 10 km during this time. In theory, reefs supplied by recruits from protected areas should be able to sustain a relatively high level of fishing pressure (Foale and Day, 1997). To apply this type of management, a sound knowledge of local currents is important in identifying good candidate areas for protection. Given the geographic scale between 'source' and 'sink' areas, the potential effectiveness of management efforts in this regard would be improved by working with multiple community marine tenure sites within a region. The establishment of closed areas in neighbouring communities could maximise the effectiveness of this strategy.

Permanent, temporary and serial closures can be enhanced by the transplantation or introduction of adult *Trochus* from other reef areas where they are less depleted (Murphy et al., 2010; SPC, 2011). Given the susceptibility of *Trochus* to the Allee effect (Foale and Day, 1997; Foale, 1998), a localised area protecting a high concentration of mature individuals is likely to increase the fertilisation success per individual and could prevent recruitment failure for down-current 'sink' reefs. While the restocking of trochus in closed areas through farming was flagged as a potential management option in the small-scale fisheries stakeholder's meeting, the procurement of animals from overseas trochus hatcheries is beyond the scope of the small-scale fisheries project.

The SPC (2011) suggest that once stocks have recovered through the introduction of adult trochus into closed areas, national regulations (i.e. size limits) can be supplemented by community actions such as the establishment of rotational harvesting. In this case, a community fishing area is divided into a number of smaller areas that are fished in rotation each year. For example, if there were four smaller areas, each area would have three years protection from being fished. Whilst apparently similar to serial closures, rotational harvesting is confined to smaller areas, such as within the marine tenure of a particular community, and rotational 'zones' would be adjacent. The close proximity of zones would enable juvenile recruitment between zones.

It is worthy of note that the management options described for Trochus are also applicable to green snails (*Turbo mamoratus*), another valuable shellfish found in New Ireland waters.

## 3.5 ROCK LOBSTER

### 3.5.1 Fisheries Information

The family Paniluridae comprise 49 species of benthic spiny rock lobsters distributed widely across tropical and temperate regions of the world. Cobb and Phillips (1980) suggests that the family may be divided into three groups based on their distribution patterns: high latitude species, deep water equatorial species and shallow water equatorial species. The lobster fishery in New Ireland is based on five shallow water equatorial species: *Panulirus penicillatus* (double-spined rock lobster), *P. versicolour* (painted rock lobster), *P. longipes femoristigma* (blue-spot rock lobster), *P. homarus* (scalloped rock lobster) and *P. polyphagus* (dentate rock lobster). The ornate spiny rock lobster (*P. ornatus*), which constitutes the single largest lobster fishery in PNG (mainly in the Torres Strait and Central and Gulf Provinces), is also caught in New Ireland, albeit in small quantities.

In New Ireland, most lobsters are caught by diving in shallow water by hand collection or spear (WCS, 2014). This is either done during a full moon or using torches. Reef gleaning at low tide is also practiced near Kavulik (WCS, 2014). Most lobsters are for caught for commercial purposes, predominantly for mining operations at Lihir and Simberi. These sales are generally conducted through a New Ireland sales agent – Nationwide Catering Services. Surplus lobsters are sold directly to resorts, restaurants and boat charter operations by the divers themselves. While some lobsters are also consumed locally for subsistence purposes, many communities don't eat them due to customary beliefs and allergies. Lobsters for subsistence consumption are often captured using spears (Hair, 1996; WCS, 2014).

In 1983, the most common species in New Ireland was reported to be *P. versicolour* (Wright et al., 1983). However, by 1995, *P. penicillatus* was deemed to be the dominant species, constituting 98% of the total lobster catches in New Ireland over a four month sampling of catches from the Tigak Islands, northern Lavongai (including the Tsoi Islands) and Kara Nalik on the east coast of New Ireland (Hair, 1996). The predominance of P. *penicillatus* was also apparent for the 2004/05 Kavieng market survey by the NFA as the species comprised 64% of the total lobster catch (NFA, 2005a). However, more recent observations and discussions with fish buyers confirm a relative resurgence in *P. versicolor*, especially from Djaul (NFA, 2007). This is consistent with information received from community representatives at the Packard small-scale fisheries stakeholder meeting in February. Anecdotal reports suggest that the dominance of individual *Panulirus* species is highly localised and variable across the New Ireland region so assessments and market trends over the last 30 years may not reflect the relative abundance of lobsters found within individual communities. Such variability in localised species succession is likely linked to the life cycle of *Paniluris* sp whereby stock replenishment may rely on the recruitment of larvae spawned hundreds of kilometres away.

### 3.5.2 Ecology

Spiny lobsters live in crevices on reefs or other hard substrate material. They generally reside in their dens and move out at night to feed. Panilurid lobsters are generally intraspecifically gregarious and often share dens with con-specifics of different sizes (Kanciruk, 1980). The largest male within a group inhabiting a den will often guard the entrance. Tropical panilurid lobsters generally have lower population densities than temperate panilurids (Kanciruk, 1980).

George (1974) examined the preferred habitats of panilurid lobsters in tropical shallow-water Indo Pacific waters. The following observations were made: *P. penicillatus* prefers rock shelters in the outer reef zone; *Paniluris longpipes* lives in hard substrate in deeper water; *Paniluris versicolour* lives among the corals as well as in deeper water on outer reef slopes, and; *Paniluris ornatus* is found from shallow lagoons to continental shelves. It is also thought that for some species, including *P. penicillatus*, females prefer shallower habitats than male lobsters (Hair, 1996). Furthermore, among shallow water tropical panilurids, there is often a size gradient with depth with larger individuals preferring deeper water (Cobb and Phillips, 1980). This may be linked to spawning: for species that don't undergo spawning migrations, deeper waters are generally associated with distance from shore and therefore access to oceanic currents facilitating larval dispersal (Cobb and Phillips, 1980).

Contrary to the perceptions of some that lobsters are scavengers, spiny lobsters feed on organisms with limited mobility such as sea snails, clams, crabs, sea urchins and coralline algae (SPC, 2011). Having poor eyesight, the primary method of food identification is chemoreception using the antennae and the tips of the periopods (Cobb and Phillips, 1980). Natural predators vary according to lobster size. As adults, octopus, sharks, skates, moral eels, large snappers, groupers, triggerfish and loggerhead turtles have been known to predate on rock lobsters (Cobb and Phillips, 1980).

### 3.5.3 Reproduction and Life Cycle

Panilurid lobsters become mature adults within 3 to 5 years and live for about 10 years (SPC, 2011). The different species of equatorial shallow water rock lobsters have similar life cycles. They have separate sexes and the size at sexual maturity is dependent on species and location (SPC, 2011). Females of *P. penicillatus* have been reported to reach sexual maturity at 65mm carapace length (CL) in New Ireland (Hair, 1996) while sexual maturation sizes of female and male *P. versicolour* were reported to be 66mm CL and 72mm CL, respectively (George and Foreman, 1976). Egg carrying capacity is related to female size: it is estimated that around 800 eggs are produced per gram of female body weight (Cobb and Phillips, 1980). Also, larger female lobsters breed more frequently as they increase in size (Hair, 1996).

Some species, including *P. penicillatus* (Hair, 1996) appear to breed throughout the year, sometimes with a peak in the warmer months. Male lobsters transfer a sperm packet (spermatophore) to the female. The female releases many thousands of eggs which are fertilised as they pass over the sperm packet. The eggs are carried for about one month and the females of some spiny lobster species, including *P. ornatus,* undergo an extensive offshore migration to release their eggs. The fertilised eggs are carried for about a month before hatching as planktonic phyllosoma, which drift for between six and twelve months. Less than one in every thousand phyllosoma survives to settle on the sea floor as a juvenile lobster while less than one in every hundred juveniles survives to become a mature adult (SPC, 2011).

As for juvenile and adult lobsters, phyllosoma grow by moulting their exoskeleton and reforming a larger one. Phyllosoma may undergo up to 17 moults before recruiting to suitable substrate habitats as peurelus. It is though that phyllosoma may postpone their final larval moult until suitable habitat is found to metamorphise into puerelii. At this stage, purelii are morphological similar to juvenile and adult lobsters but lack pigmentation. After another moult, the puerelus becomes a juvenile lobster and is fully pigmented.

### 3.5.4 Current Regulations

Fishing, trading and export of lobster are guided by rules set under the National Lobster Fishery Management Plan developed by the National Fisheries Authority. A total tail minimum length of 100mm applies for *P.versicolour*, *P.longipes* and *P.homarus*, while a total tail minimum length of 115mm applies for *P.ornatus*. Furthermore, all species of rock lobster with a tail weight of less than 169 g or an overall weight of less than 409 g cannot be harvested and exported. The size limits are set at a size above sexual maturity, allowing for lobsters to spawn at least once before entering the fishery. However, personal observations of lobsters for sale at Kavieng restaurants would suggest a degree of local non-compliance with NFA size limits. Furthermore, at the February stakeholders meeting for the Packard fisheries project, the lack of knowledge about lobster size limits among staff from fisheries authorities and those involved in commercial fisheries marketing highlights an apparent deficiency in the awareness of essential information.

The NFA prohibits the taking of berried females. Also, commercial buyers must be issued with a licence from the NFA and there are limits on the number of licenses issued in each province. However, based on information sourced from the NFA, it appears that the use of hookah and SCUBA gear to collect lobsters is not prohibited, unlike for trochus and green snails. Size limits are restrictions on the capture of berried females do not apply to lobsters for subsistence consumption.

### 3.5.5 Management Options

Community representatives at the February Small-Scale Fisheries Stakeholder Meeting identified three potential options for lobster management in NIP:

1. Public/community awareness of existing regulations (min sizes, harvesting berried females, destructive fishing practices) and more general info on species' status and threats
2. Develop/encourage alternative income sources for communities fishing depleted areas
3. Investigate measures of transferring localised fishing pressure to less fished areas

These options will be discussed in view of available literature and other management alternatives to sustain small-scale shellfish fisheries and dependent livelihoods in New Ireland.

Given the exceptionally long period of phyllosoma development and dispersal, coupled with prevailing oceanographic forces, local efforts aimed at increasing the spawning success of local lobster populations are not likely to repopulate nearby reefs (which may reflect the apparent lack of available literature on small-scale spiny lobster management). This aspect of their life cycle erodes the effectiveness of protected area management in a community management tenure context, despite the success of protected areas in conserving rock lobsters in centrally managed open access fisheries (Acosta, 2002). At a community level, potential benefits might accrue if a network of protected areas were established throughout the region (particularly if patterns of larval dispersal are better understood). However, it is likely that larval dispersal ranges may exceed even New Ireland regional scales relevant to the current Project. Besides, there are likely to be sufficient unfished or lightly fished lobster populations within the broader region to enable successful juvenile recruitment on New Ireland reefs (Hair, 1996). This supposition is supported by fact that most fishers in the region collect lobsters while snorkelling (and not SCUBA), limiting access to deeper water brood stock.

Despite this, there are ways in which communities may maximise the value of lobsters recruited to local reefs. In addition to supporting national regulations, such as size limits and catch prohibitions on berried females, communities could take the following actions:

- Restrict the total community catch of lobsters to a sustainable level. The SPC (2011) suggests that a sustainable catch maybe as low as 20 kg of lobster per km of reef-face per year. This option would, however be difficult to implement and enforce and would likely require extensive stock assessments to be undertaken at each participating community.
- Within each community, implement a system of annual rotational harvesting within area subdivisions. Each area could be fished for one year and then left unfished for a number of years.
- Ban the use of spears as a harvest gear. Collecting lobsters by hand allows fishermen to return small and berried lobsters. The use of spears appears to be more widespread in fishing efforts for subsistence consumption.

All of these measures effectively aim to restrict harvesting to larger lobsters, in which case the NFA size limits should provide sufficient protection given adequate levels of compliance. Based on anecdotal reports of non-compliance with NFA size limits by New Ireland fishers, encouraging compliance would be a high priority management option if lobsters were considered as a candidate species group. Education programs, whist focussing on size limits, could also address unsustainable practices such as the capture of berried females and the removal of eggs from lobsters destined for sale. Hair (1996) suggests that fishing communities could be supplied with lobster measuring gauges. There may also be scope to collaborate with the NFA and/or New Ireland Provincial Fisheries to assess whether the lobsters purchased by local buyers conform to existing regulations. If such collaborations were possible, practices such as the removal of eggs from berried females[3] and the holding of females in cages until they have shed their eggs (Hair, 1996) could be investigated.

Even if local (or regional) improvements in lobster recruitment do not result from management efforts, the harvesting of larger individuals would value-add to fishers catches in the longer term, especially as adult and sub-adult rock lobsters have a high degree of site fidelity and territoriality (Cobb and Phillips, 1980) i.e. smaller (and therefore less valuable) lobsters left unharvested will likely remain in the same area until they are of a harvestable size, notwithstanding natural mortality effects.

[3] According to Hair (1996), the removal of eggs is widespread in New Ireland and is quite obvious when this has been done. It is also implied by Hair (1996) that buyers often buy these lobsters.

# 4 DISCUSSION

The purpose of this document is to evaluate the amenability of candidate species groups to small-scale community based management in the New Ireland Province of Papua New Guinea. In doing so, the characteristics of both community based management (as opposed to fisheries management at a different scale) and candidate species groups (in particular, their ecological characteristics) were considered. In effect therefore, management options described as having success potential were those deemed to be a 'good fit' between available information on species ecology and life history and the capacity of community based management to deliver beneficial conservation and livelihood outcomes in this regard.

Some of the information sourced for this document enabled confident assessments of the likely effectiveness of community-based management options for particular species groups. However, some assessments were 'educated guesses' based on supporting information. Regardless, uncertainties surrounding a multitude of variables relating to the ecological and social aspects of considered management measures means that supported options are more prospective than prescriptive. Accordingly, no effort was made to provide a more rigorous and/or quantitative approach in assessing the relative suitability of each group to small scale community-based management. However, modelling the impacts of management interventions may be considered at a later stage. Nonetheless, based on the assessments provided for each group, a 'sliding scale' of suitability may be made with sufficient confidence at this preliminary stage. This scale, from most suitable to least suitable, is as follows: *Trochus* (and green snail); mud crabs; rabbitfish; trevallies; and spiny lobsters. The reasons for the rankings are outlined below.

### TROCHUS (AND GREEN SNAILS)

The low mobility of these animals, coupled with their occupation of shallow inshore habitats makes them particularly susceptible to localised exploitation. Their ease of capture and high value, which also makes them vulnerable, highlights the potential benefits that may accrue at the community level under an effective management strategy. While NFA regulates minimum size limits, the sustainability challenges facing the fishery infer that this measure, alone, is insufficient to address the balance between population densities and minimum threshold sustainability densities advocated by the SPC and CTI. It may also infer a low level of compliance, which may be addressed to some degree by more effective education and awareness measures – this was highlighted as a priority action at the community level in the Melanesian region by Foale (2006; 2008).

The likely success of temporary and/or permanent closed areas, as advocated for both *Trochus* and green snails by Foale (1998), is consistent with the long-standing traditional use of Tambu areas in New Ireland. As such, the community management structures already exist for this course of action. The perceived effectiveness of closed area management is further underpinned by the short larval stage of both *Trochus* and green snail. As such, 'source' areas are likely to be close to 'sink' areas, providing incentive for local communities to conserve a considerable proportion of mature stock to prevent local recruitment failure. The stocking of closed areas with Trochus sourced from surrounding areas should also be considered.

### MUD CRABS

Characteristics of the mud crab fishery that would facilitate the effectiveness of small scale management efforts include the localisation of habitats (mangrove systems), the limited movements of crabs post-settlement, the economic and cultural importance of crabs to mangrove based communities, the limited capacity for non-mangrove communities to exploit the resource, and the availability of relatively simple and potentially effective management options. Some of these options have already been incorporated into the management plans of some locally managed areas in New Ireland, which may allow their effectiveness to be assessed. Furthermore, the progression of mud crabs as a candidate species group for the Packard fisheries project would enable collaborative and synergistic efforts with the MARSH project. Whilst the resource sharing potential may save time and money, common objectives include the sustaining of fisheries livelihoods and mangrove protection.

Perhaps the most prominent limitation of managing mud crabs at a local scale is the duration of larval development and dispersal. This means that crabs spawned in one area are likely to settle in other areas. This may provide a community disincentive for measures that aim to maximise spawning success, such as a prohibition on the harvest of berried females and the implementation of protected areas. While this may be addressed, in part, by management co-operation between mangrove based communities within the wider region, doing so imparts additional effort, complexity and uncertainty. In terms of effort and complexity however, this may be attenuated somewhat by co-operative efforts with the MARSH Project and the existence of mangrove based locally managed areas already in the region.

Based on the information reviewed in this report, the preferred management options for mud crabs are the implementation of size limits, a prohibition on the harvest of berried females and the protection of mangrove habitats. These are also the three preferred measures advocated by the SPC (2011) for small-scale community based mud crab management. Also deemed to have potential conservation value in this context are the establishment of protected areas (particularly protected area networks), rotational harvesting within locally managed areas and a prohibition on the harvest of female crabs. As community based management regimes are essentially flexible and adaptive (Wamukota et al., 2012), 'second tier' management measures may be considered if 'first tier' measures are deemed to be ineffective. The existence of current locally managed areas in New Ireland with restrictions on the harvest of sub-adults and berried females may enable a comparative analysis with unmanaged sites to be made. This would inform the current project by assessing whether such measures have been successful in increasing crab size and abundance. The WCS mud crab market survey could also be examined and extended to provide necessary information to inform management interventions. In addition to examining the effectiveness of previously implemented management measures, local research efforts deemed instructive for the current project should be aimed to address the following issues: size at sexual maturity, spawning seasonality, distance of spawning migrations for female crabs, larval dispersal, rates of growth and natural mortality, and the impact of current harvesting practices on mangrove habitats

## RABBITFISH

In addition to being important to subsistence and artisanal fishers, incentives to sustain healthy rabbitfish populations include their apparent iconic status in New Ireland, their role in keeping coral free of suffocating plant growth and the maintenance of a relatively energy efficient source of protein for New Irelanders. The life history characteristics of rabbitfish, including a fast growth rate, short life span and high turnover rate suggest that rabbitfish will respond rapidly to effective management interventions. This has been demonstrated in response to gear management and protected areas (McClanahan et al., 2008; McClanahan and Hicks, 2011; Hamilton et al., 2004). Sustaining healthy exploitable populations of rabbitfish is also likely to reduce potential impacts on species more vulnerable to fishing such as cods, groupers, emperors and snappers.

The preferred management options for rabbitfish are gillnet mesh size reductions and periodic closures of spawning sites. Given the apparent widespread distribution of rabbitfish in New Ireland, the first option could be widely adopted amongst participating communities, despite potential problems in doing so discussed in Chapter Six. Reducing mesh sizes would also confer likely benefits for other fish species. The implementation of spawning closures however, is only applicable for marine tenure sites that encompass rabbitfish spawning areas. There may also be challenges encouraging the acceptance of spawning closures by participating communities as they could be competitively disadvantaged in the short-term by not fishing aggregations while increasing recruitment to the benefit of surrounding areas. Such problems may however be alleviated by engaging the participation of multiple adjacent communities (discussed later).

The diversity of biological and ecological characteristics among siganid species found in New Ireland waters poses numerous management challenges. As such, it would be preferable to target management efforts at the guild or species level. In this regard, efforts should focus on the species dominating local catches – the gold-lined rabbitfish (*Siganus lineatus*) – and possibly other seagrass associated species such as *S. argenteus* and *S. fuscesens*. However, numerous uncertainties will need to be addressed before management strategies can be refined. Most prominently, observed changes in rabbitfish populations in recent years will need to be understood at the species level. Following from this, local research efforts could focus on gear selectivity (for species and size), the location of spawning aggregation sites, and species' home ranges and site fidelity.

## TREVALLEY

The low degree of site fidelity of these highly mobile long ranging fish, coupled with their non-ubiquitous distribution poses challenges for the management of trevally at a community level. Nonetheless, the preferred management options are gillnet mesh size reductions and periodic closures of spawning sites. Feedback from the February stakeholders meeting suggests that trevalley are actively targeted by nets (and lines and spears) when large schools of baitfish are observed. Without knowing the mesh sizes that are currently being used, it is not possible to determine whether they are large enough to allow the passage of sub-adult fish, though one study suggests that they would not (McClanahan and Cinner, 2008). However, given the relatively large size of adult trevalley it is highly likely that a mesh size large enough to allow for the passage of sub-adult fish would be acceptable to fishers in a multi-species fishery. Regardless, numerous obstacles in considering such measures within isolated management areas were identified in Chapter 5, reinforcing the advantages of managing these highly mobile fish at a wider geographic scale encompassing numerous adjacent communities.

If spawning sites are identified within waters managed by participating communities, temporal spawning closures should be considered. However, there may be challenges implementing this as participating communities could be disadvantaged in the short-term by not fishing aggregations while increasing recruitment to the benefit of surrounding areas. Again, this highlights the advantages of potential fishery management 'trade-offs' that could be implemented if managing a number of adjacent communities at a broader scale.

## SPINY ROCK LOBSTERS

Benthic invertebrates with low mobility and high site fidelity are generally conducive to small-scale community based management. For spiny rock lobsters however, the exceptionally long periods of larval dispersal effectively preclude local management efforts to repopulate local reefs (i.e. protected area management) as 'source' areas are generally located a long way from 'sink' areas. Depending on oceanographic forces, larval dispersal distances may even negate management efforts at a regional level. Despite this, there are ways in which communities may maximise the value of lobsters recruited to local reefs. Fortunately, the most obvious measure –which is potentially the most effective measure – is relatively straightforward: encourage compliance with national regulations on size limits and catch prohibitions on berried females. There may also be scope to collaborate with the NFA and/or New Ireland Provincial Fisheries to assess whether the lobsters purchased by local buyers conform to existing regulations.

Communities are able to add value to lobsters recruited within their waters by harvesting them at a larger size, as they are unlikely to leave their dens given their high level of site attachment. Further research on the natural mortality of tropical panilurid lobsters may further inform the benefits that may accrue by doing this. Given the livelihood benefits likely to accrue to communities who refrain from harvesting lobsters until they are of a larger size, the advantages should be relatively easy to convey through education and awareness efforts.

# 5 CONCLUSIONS

This report has attempted to narrow down the five species groups identified during the stakeholders meeting to three species groups most suitable for community based management in New Ireland. While *Trochus* (and green snails), mud crabs and rabbitfish were deemed to be the most suitable, ignoring trevalley and rock lobsters may represent a missed management opportunity. If resources permit, management interventions pertaining to all five species groups should be considered under management plans, legislation or other management instruments facilitated by WCS under the Packard small-scale fisheries project. Due to resource constraints however, research efforts designed to better understand local fisheries should be restricted to shellfish, mud crabs and rabbitfish.

In addition to identifying preferred species groups for the small-scale fisheries project, this report outlines preferred management options for five fisheries based on local and non-local research and with a view to the limitations and opportunities available under small-scale community co-management arrangements. It also presents a rudimentary research schedule framed by knowledge gaps identified. Further detailed information from participating communities on fishing practices and temporal trends in the status of individual species will also be required to guide and refine management and research efforts. At this stage however, it seems that some of the 'short-listed' management options may provide conservation benefits for more than one species group, including species groups not examined in this report. For example, tambu areas for conserving trochus and green snail broodstock could also encompass sensitive habitats for other species groups. As another example, an increase in gill net mesh sizes could benefit both rabbitfish and trevally populations, as well as many other types of fish. Furthermore, reducing the use of nets over reef areas could have the added benefit of reducing coral deterioration – through direct damage to corals by retrieving nets (McClanahan and Cinner, 2008) and by reducing the depletion of herbivorous fish (Campbell et al., 2002).

A significant limitation to the management of fisheries at a community scale is a mismatch with the geographic scales apparent for many fisheries. As such, the greater conservation opportunities that are likely to be realised under a system of management co-operation between a number of adjacent communities has been a pervading theme in this report. Managing fisheries in isolation may facilitate sustainability outcomes for sessile invertebrates with short periods of larval dispersal; however, the scope for success is more limited for other species in this context. Also, at a smaller scale, the area under marine tenure may not encompass all key habitats for a species, including those occupied at vulnerable life stages. Broader scale management will expand the geographic scales necessary to apply effective management controls for species that occupy habitats beyond those under the tenure of individual communities. A broader scale approach would also make management measures that disadvantage a community (in terms of catches) more attractive to implement through a system of management 'trade-offs'. Here, harvest constraints imposed on one community may be compensated by the benefits to that community from harvest constraints from other communities within a network of cooperating communities. Such a system could also facilitate a greater level of compliance as fishing activities may be monitored between adjacent communities and/or may engender a culture of mutual reciprocity in terms of 'doing the right thing'. Also, without management participation from neighbouring communities, compliance may be fleeting as cooperating communities may perceive that they are fishing with a competitive disadvantage. While this approach to management will impart additional logistical considerations and complexities, the potential for successful outcomes is considerably greater than managing communities in isolation. The apparent receptivity among communities that occupy the Tsoi Islands may represent an opportunity to investigate such an approach

In synergy with research and management efforts, education and awareness programs are required in participating communities to facilitate a better understanding of the vulnerability of exploited fisheries and the role of management interventions to sustain them and the livelihoods that depend on them. Such efforts are necessary to gain an appreciation for and compliance with management measures. According to Foale (2006, 2008), education programs should focus on the 'invisible' part of the fishery: that is, the role of spawning and larval dispersal in repopulating local fisheries. Based on fisheries co-management arrangements in the Melanseian region, Foale (2006, 2008) suggests that while fishers generally have an intricate knowledge of the 'visible' fishery, a lack of understanding of the link between reproductive stock density and recruitment success often leads to a sense of fatalism over harvest declines and may undermine compliance with management interventions. It is hoped that the management, research and education strategies developed for the small-scale fisheries project will enable sustainable fisheries and livelihoods that may serve as a template for community fisheries management throughout the greater region.

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