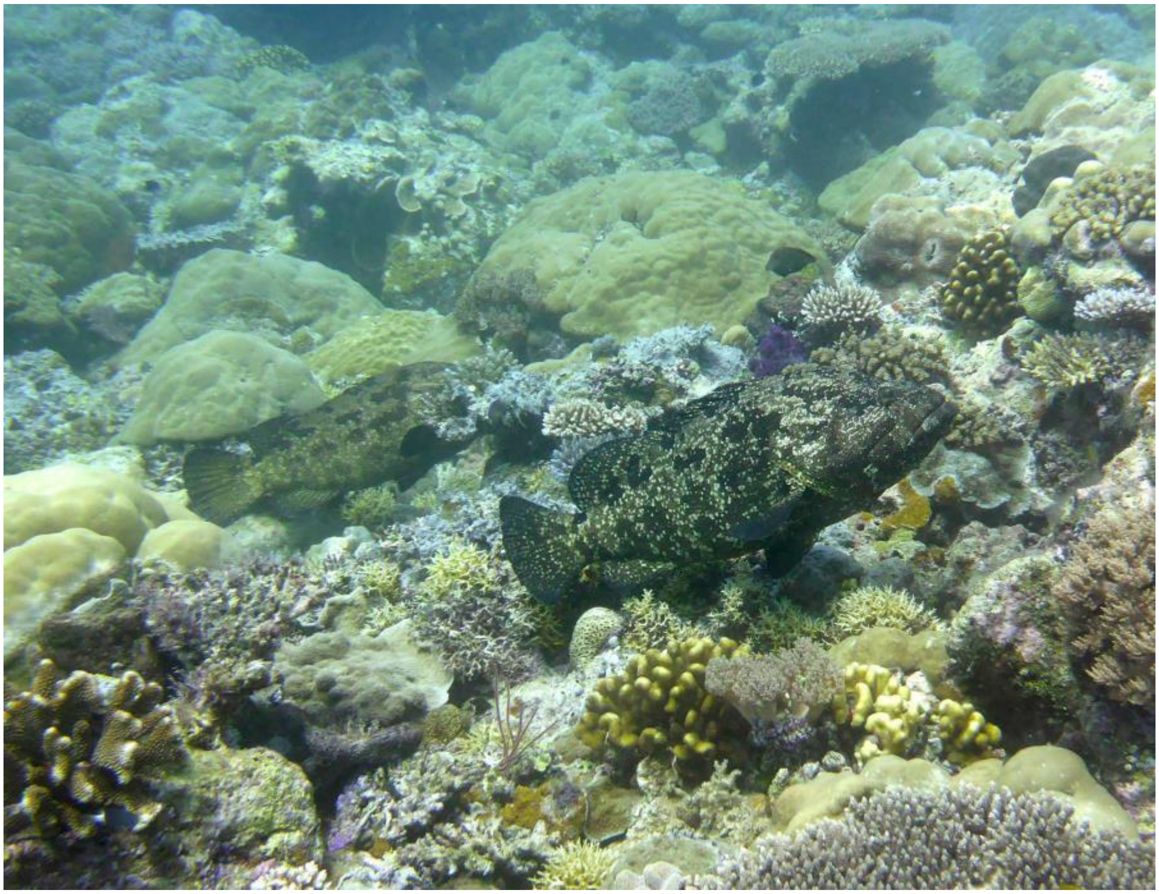
Grouper Spawning Aggregations: the effectiveness of protection and fishing regulations



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Abstract

In Palau, regulations are implemented to manage groupers and protect spawning aggregations. They include a seven-month closed season on grouper fishing during the main spawning season, and the permanent spatial closure of the two main fish spawning aggregation (FSA) sites. Since 2008, underwater visual census surveys were conducted at these sites and two additional unprotected reference sites, two and three days before the new moon lunar phase to monitor the abundance and biomass of groupers over time. Overall, our results demonstrated that, protected FSAs harbor significantly more groupers (up to 9 times higher) than reference sites during spawning times. Within the two FSAs, the abundance of *Epinephelus fuscoguttatus* (Meteungerel'temekai) increased over time and there was an increasing trend of *Epinephelus polyphekadion* (Ksau'temekai) at one of the FSAs. There was no change in abundance of *Plectropomus areolatus* (Tiau) but we observed high inter-month variability in their aggregative patterns. Despite some limitations, this study proves that management strategies currently implemented in Palau are effective and should be maintained. However, additional studies are needed to better understand the spawning aggregation patterns of *P. areolatus* in order to properly assess the effects of current management regimes on this species.

Introduction

Several species of coral-reef fishes aggregate to spawn during specific times and at specific locations (Domeier and Colin 1997; Sadovy and Domeier 2005; Domeier 2012). This reproductive period is related to the lunar phase and occurs at the same place, where the density of fish far exceeds the density during non-reproductive period (Domeier and Colin 1997; Domeier 2012). Many commercially-valued fish species such as grouper (Epinephelidae), snapper (Lutjanidae), jack (Carangidae) and surgeonfish (Acanthuridae) share this life history trait (Domeier and Colin 1997; Sadovy de Mitcheson et al. 2008). Because of the predictability of fish spawning aggregations (FSAs) in time and space, fishermen often target them. Depending on the intensity of fishing, the extraction of spawners during their reproductive time can significantly affect the local population (Sala et al. 2001; Sadovy and Domeier 2005; Rhodes et al. 2014).

Among coral-reef fish that are known to aggregate to spawn, groupers (Epinephelidae) are highly valued food fish on local and live-fish food trade markets (Sadovy and Vincent 2002). In addition to their spawning behavior, groupers have other life history traits that make them vulnerable to fishing pressure. They are slow growing and long-lived, reaching sexual maturity late in life (Sadovy and Vincent 2002). Groupers are also protogynous hermaphrodites (changing sex from female to male during their lifespan), which can lead to uneven sex ratios if fishers disproportionally target the largest individuals in a population, resulting in sperm limitation (Koenig et al. 1996; Armsworth 2001; Gruss et al. 2014). Worldwide, grouper FSAs have declined (Sala et al. 2001; Sadovy de Mitcheson et al. 2008; Golbuu and Friedlander 2011; Rhodes et al. 2014) or, in some cases, have become locally extinct (Aguilar-Perera 2006; Sadovy de Mitcheson et al. 2008, 2013) due to unsustainable fishing practices.

Several management strategies have been proposed to reduce grouper population declines. These include size limits, seasonal closures, total specific species bans, gear restrictions, and fishing closure of spawning sites (Domeier and Colin 1997; Rhodes and Sadovy 2002; Sadovy de Mitcheson et al. 2008; Gruss et al. 2014), and some methods have shown to be effective (Nemeth 2005; Hamilton et al. 2011). Among those, in Palau, two methods have been implemented to manage grouper populations: two known FSAs sites are closed to fishing all year round, along with a seasonal fishing closure of seven months a year for five species of groupers.

In Palau, groupers have historically been targeted as food fish species (Sadovy de Mitcheson et al. 2008; Golbuu and Friedlander 2011). However, their aggregation characteristics have also been well documented (Johannes 1981; Johannes et al. 1999; Golbuu and Friedlander 2011); hence the implementation of fishing regulations strategies. “Since 1994, the Palau Marine Protection Act of 1994 banned fishing, selling, buying and possession of five species of grouper (*Epinephelus fuscoguttatus*, *Epinephelus polyphekadion*, *Plectropomus areolatus*, *Plectropomus laevis* and *Plectropomus leopardus*) during the summer months of April through July” (Golbuu and Friedlander 2011), which was extended to October in 2012. In addition, two well-known spawning sites are closed to fishing all-year round: Ngerumekaol Spawning Area (NSA) and Ebiil Conservation Area (ECA) (Fig. 1). NSA has been temporarily closed during the summer months since 1976 and became a year-round no-take zone in 1999. ECA was first classified as a no-take no-entry zone in 2000 but is now opened to non-extractive diving and snorkeling activities.

This present study examines the effectiveness of management strategies on the four principal grouper species present at spawning locations: *Epinephelus fuscoguttatus (*Meteungerel’temekai), *Epinephelus polyphekadion (*Ksau’temekai), *Plectropomus areolatus (*Tiau), and *Plectropomus laevis (*Mokas/Katuu’tiau). The objectives of this study are 1) to compare abundance and biomass at protected areas versus non-protected FSA reference sites, and 2) to examine trends in abundance and fish size distribution at protected FSAs over time.

Methods

Study Sites

Underwater Visual Census (UVC) surveys were conducted at four different sites: two marine protected areas (MPAs) and two non-protected sites (Fig. 1). Both MPAs are important aggregation sites for *Serranidae* species. NSA encompasses a dead-end channel with a mean depth of 9 m (Johannes et al. 1999) and covers an area of 3.51 km^2, which was closed to fishing in 1999. ECA includes a 400 m-wide, deep (up to 35m) channel, containing 19.1 km^2 of reef, and has been classified as no take / no entry zone since 2000. The two non-protected sites (Denges and Ngeremlengui) are also reef channels that historically possessed FSAs, but were depopulated due to overfishing practices (Sadovy 2007).

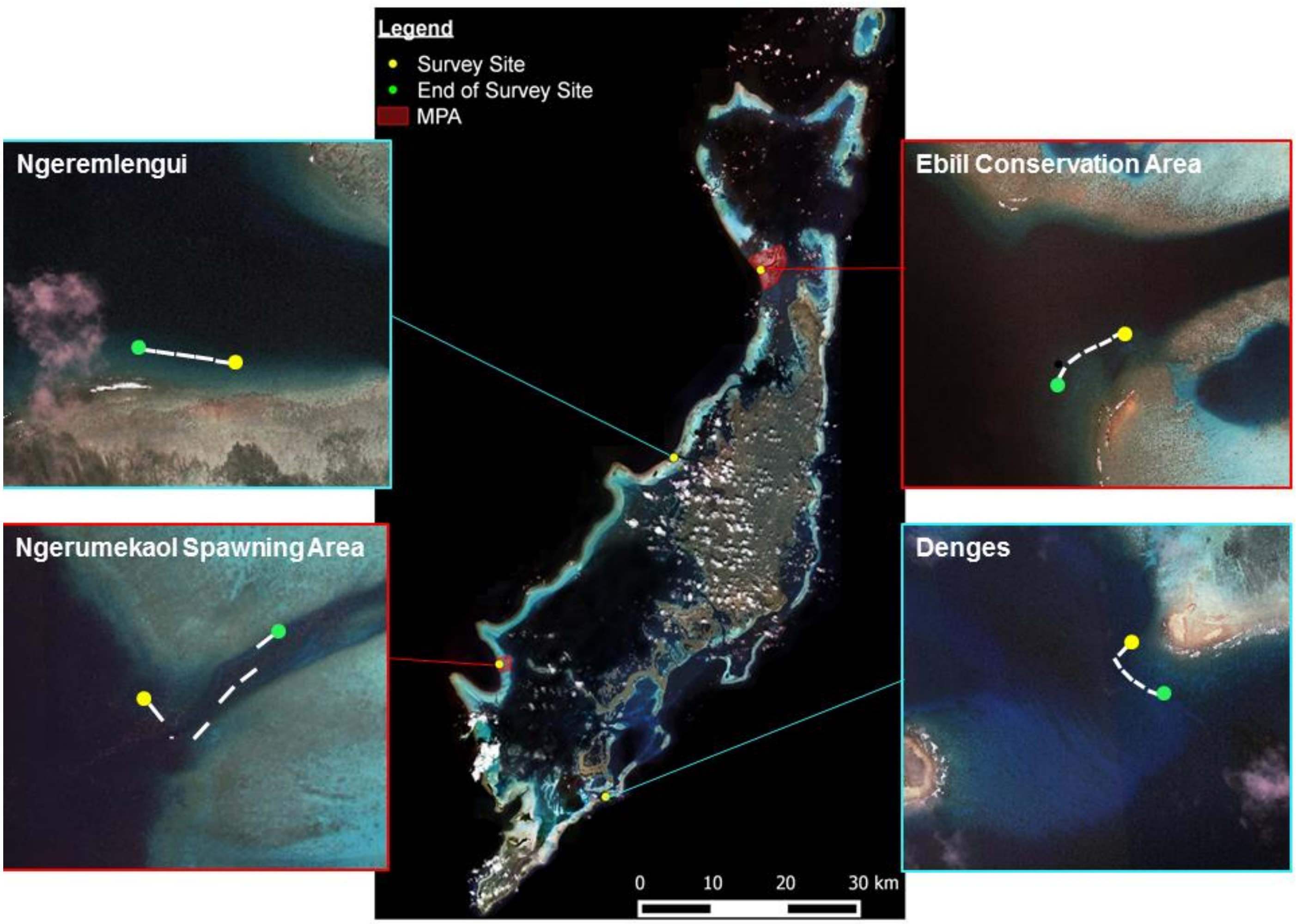

Figure 1: Satellite map showing four survey sites and positioning of the five 50 m transects. Protected sites framed in red, reference sites framed in blue. GPS coordinates of survey sites are in Appendix 1.

Sampling Design

UVC surveys were conducted at the same lunar phase each month, two and three days before new moon as advised in Johannes et al. (1999), for ECA and NSA respectively. In 2008/2009 and 2014/2015, year-round monthly surveys were completed (with the exception of January 2009, July 2009/2014 due to adverse weather conditions). In 2012 and 2013, only the months during the peak of the spawning season were surveyed (May to September).

At each site, five 50 m permanent transects were surveyed each month (Fig. 1). The first transect was marked using GPS coordinates and distinct reef structures and followed a constant 10 m depth contour along the reef. The following transects were placed approximately five meters after the previous transect, or at specific reef marks known by the observers. Only ECA was surveyed at an additional depth (20 m) due to the large size of the channel. Observers recorded the abundance and estimated the total length of selected *Serranidae* species to the nearest centimeter within the five 50 m x 5 m transect belt (250 m^2), while swimming at a measured constant speed. Six different observers were used during the time span of the sampling, after prior species identification and size estimation training.

Species specific fish biomass was calculated using the total length-based equation: $W = aTL^b$, where W is the weight of the fish in grams, TL the total length (cm) of the fish, and a and b are constant values obtained from published biomass-length relationships (Kulbicki et al. 2005) and FishBase (www.fishbase.org).

Data analysis

To assess the effect of protection on grouper's abundance and biomass, linear mixed effects models were fit using the "lme4" package in R (Bates et al. 2013; R Development Core Team 2015).

To compare protected with non-protected FSAs, linear mixed models were fit for the abundance and biomass data of four common grouper's species: *Epinephelus fuscoguttatus*, *Epinephelus polyphekadion*, *Plectropomus areolatus*, and *Plectropomus laevis.* Status (two levels: protected and non-protected) was set as fixed factor with month as a random factor nested within site and year to address the variation associated with repeated measurements at the same sites over time. To examine the trends in grouper's abundance at protected FSAs over time, similar models were fit to the abundance of the same grouper species with Year as a fixed factor and Month as random factor nested within Year. Data was first log+1 transformed to conform to model assumptions of normality and homogeneity of variance. When refuted, general linear mixed models (GLMMs) with a negativebinomial distribution were chosen instead of linear mixed effect models. For all models, differences among the levels of the fixed factors were further examined using the “ghlt” function within the “multcomp” package (Hothorn et al. 2008). The size distribution of each species was plotted (proportional density curves) for each year and mean sizes were calculated in R. However, we interpreted this data with caution due to the large number of observer (n = 6) during the study.

Results

Effect of protection

The overall abundance and biomass of groupers over all the years of surveys was significantly higher within protected sites (NSA and ECA) compared to their respective reference site ($P < 0.001$) (Fig. 2). The two protected areas were also significantly different from each other ($P < 0.01$), with greater biomass/abundance of grouper at NSA compared to ECA, while the two reference sites did not differ ($P > 0.05$).

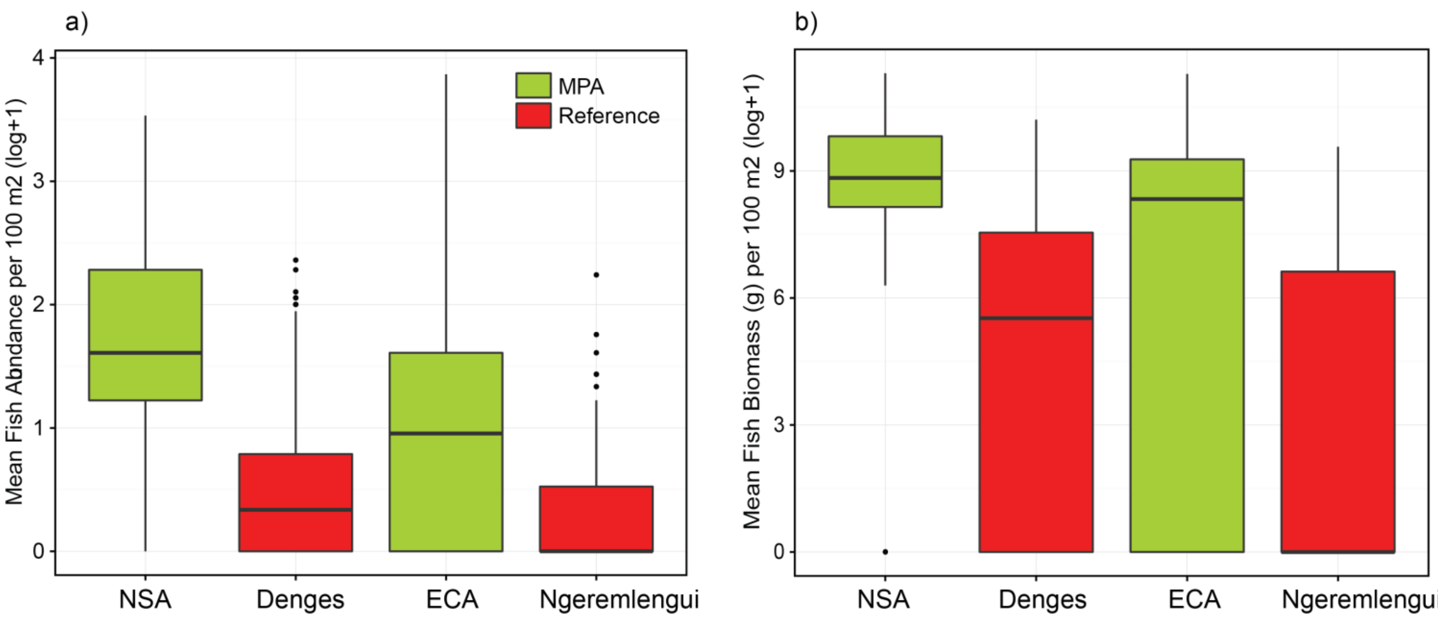

Figure 2: Boxplots of grouper abundance (a) and biomass (b) at MPAs and Reference sites on Palau. Black lines inside boxes represent the median of the sample surrounded by the upper (1st) and lower (3rd) quartiles. Points above and below the whiskers represent outliers.

Year-round abundance trends of groupers at FSAs

There was a significant increase in *Epinephelus fuscoguttatus* density in 2014/2015 compared to 2008/2009 at NSA ($P < 0.001$) and ECA ($P < 0.05$) (Fig.3). However, the density of *Plectropomus areolatus* and *Epinephelus polyphekadion* did not fluctuate significantly through time ($P > 0.05$) (Fig.3).

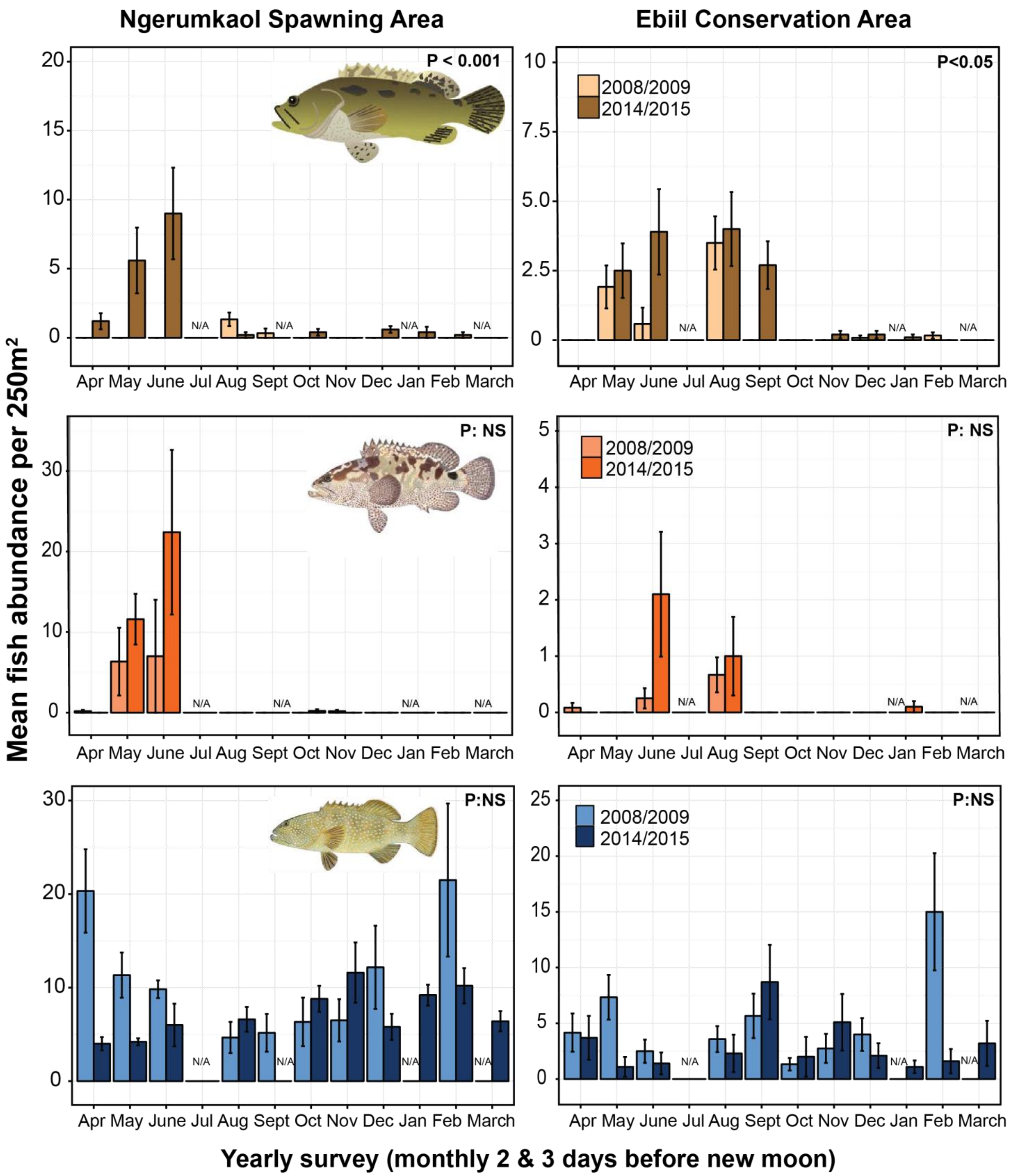

Figure 3: Mean monthly abundance of grouper species (± SE) at two sites on Palau in 2008/2009 and 2014/2015. N/A represent missing samples. Top panels: *E. fuscoguttatus*, middle panels: *E. polyphekadion*, bottom panels*: P. areolatus*.

Abundance trends of groupers at FSA during spawning season (May-September)

The abundance of *Epinephelus fuscoguttatus* significantly increase from 2008/2009 to 2013 at NSA ($P < 0.05$) and in ECA, there was an increase in all the years from 2008/2009 ($P < 0.01$) (Fig.4). The density of the other three grouper species did not change during spawning season at both protected areas through time ($P > 0.05$) (Fig.4).

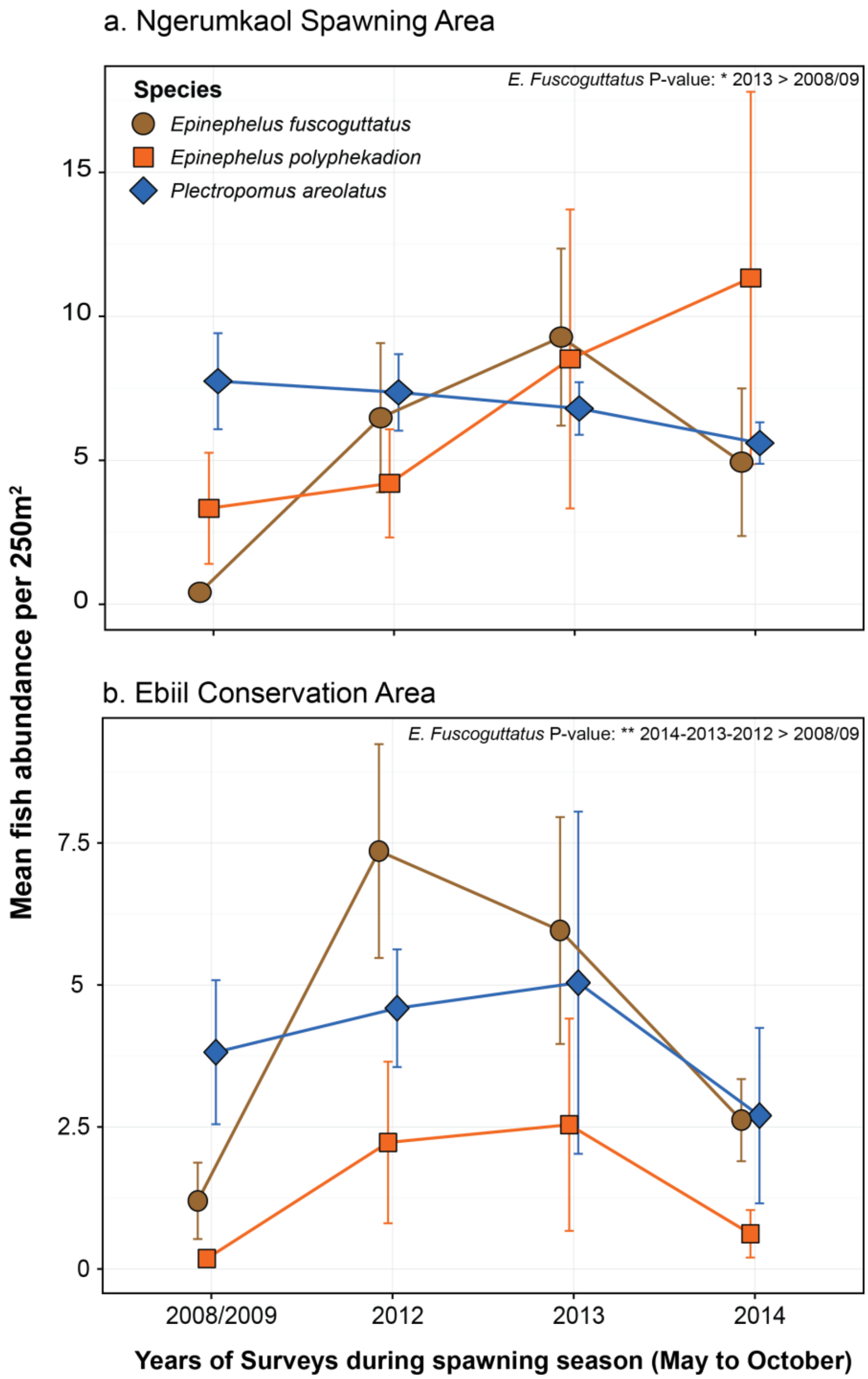

Figure 4: Mean abundance of grouper species (± SE) during the five months of spawning peak season

Grouper size distribution at FSA through time

The size distribution of each grouper species shows variable trends through time (Fig. 5). The mean size (± SE) of *P. areolatus* decreased from 48 (± 0.3) cm in 2008/2009 to 44 (± 0.4) cm in 2014/2015 at NSA, and reduced from 47 (± 0.3) cm to 41 (± 0.5) cm at ECA over the same time period. *E. fuscogutattus*' mean size went from 73 (± 3.0) cm to 63.2 (± 1.3) cm at NSA and from 70.2 (± 1.5) cm to 63.8 (± 0.7) cm at ECA through time. Lastly, the mean size of *E. polyphekadion* increased from 27.4 (± 0.7) cm to 35.8 (± 0.5) cm at NSA and did not change (35 cm) at ECA through time.

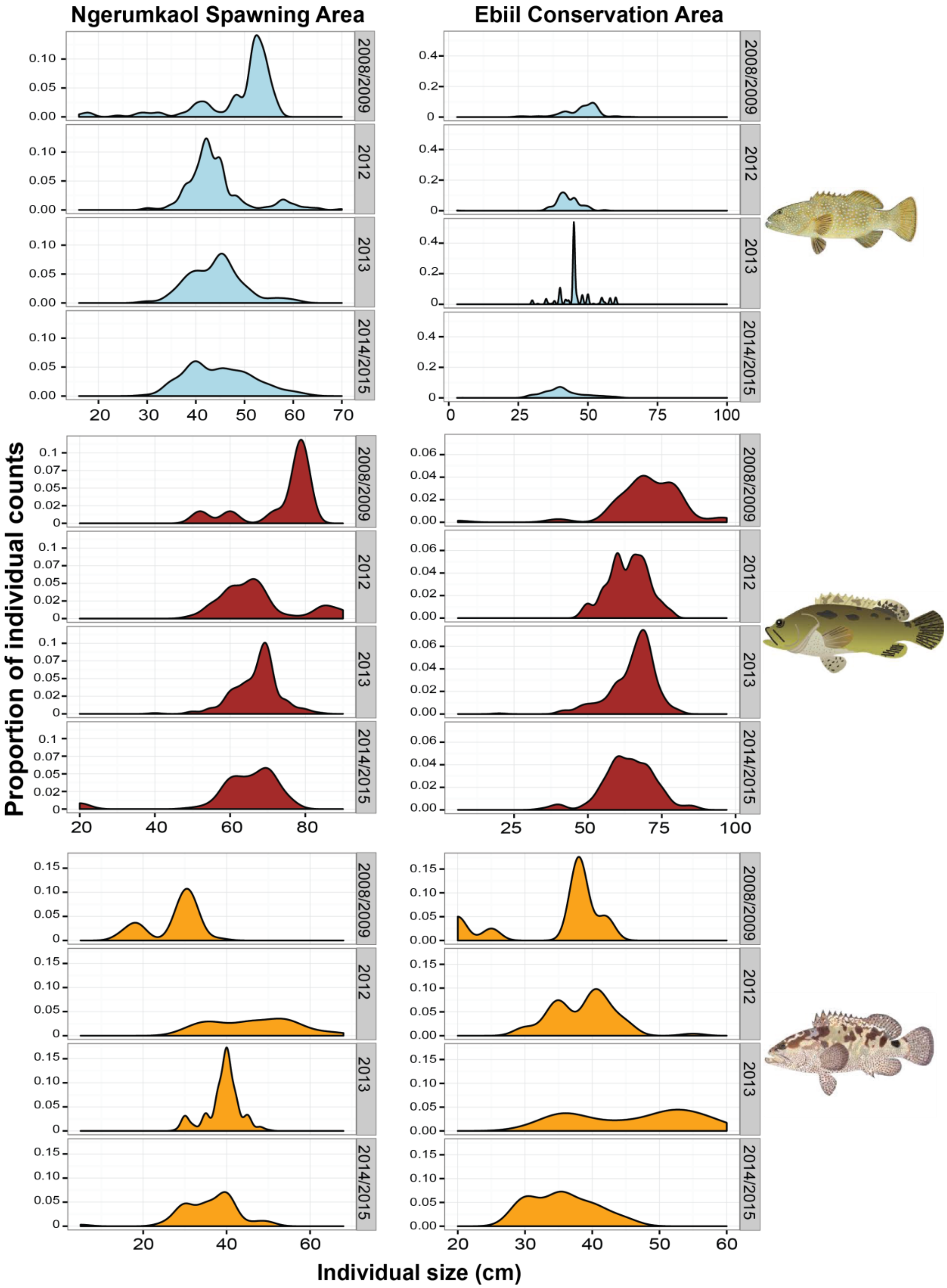

Figure 5: Density curves of the sizes of the three most abundant grouper's species at the two protected FSAs. Top panel: *P. areolatus*, middle panel: *E. fuscoguttatus*, bottom panel: *E. polyphekadion*.

Discussion

Effect of Protection

The present study highlights an overall positive effect of protection at FSAs in Palau. The abundance of groupers was seven times higher, and biomass six and nine times higher at protected FSAs (NSA and ECA) compared to their respective reference sites. The two protected FSAs, closed to fishing for over 15 years, proved to be effective at maintaining high levels of biomass, as shown by previous studies in Palau (Golbuu and Friedlander 2011), in the wider Indo-pacific region (Hamilton et al. 2011), and in the Caribbean (Nemeth 2005). Within both FSAs, the abundance of one grouper species, *E. fuscoguttatus*, significantly increased over the study period. Furthermore, even though not significant, there was an increasing trend in the abundance of *E. polyphekadion* at both FSAs, especially at NSA during the spawning peak season (June-July). In contrast with protected FSAs, no increase in groupers at non-protected FSAs was observed which implies that protection status contributed to the observed increase. Knowing that *E. fuscoguttatus* are slow-growing, the positive response to protection observed over a few years is very encouraging for the future of both protected FSAs and grouper's populations. *P. aerolatus* did not show any increase or decrease in abundance at both FSAs through time but its abundance was shown to be highly variable throughout the months of each surveyed year.

The temporal variability of spawning aggregations

Unlike the two *Epinephelus* species that showed clear yearly spawning seasonality, *P. aerolatus* demonstrated very variable abundance trends over multiple years. Groupers use moon phases as one of the environmental cue for spawning time (Johannes 1981; Johannes et al. 1999). However, the difference in timing between lunar calendar and our modern lunisolar calendar requires a correction of the addition of one lunar month every three years (Johannes 1981). We hypothesized that this discrepancy might explain the slight inter-month variability in yearly seasonality for E. *fuscoguttatus* and *E. polyphekadion*. The considerable monthly variation in abundance of *P. aerolatus* between 2008/2009 and 2014/2015 make it difficult to detect changes in the aggregation size over time, and therefore, the effectiveness of current management strategies. In contrast with both *Epinephelus* species, *P. areolatus* grows faster, matures earlier, and demonstrates inter-annual variability in spawning aggregation time (Rhodes et al. 2013). A better understanding of spawning timing of *P. areolatus* in Palau will determine the effectiveness of the current temporal fishing closure at protecting this species during its key reproductive periods. Effective monitoring of this species may require a more extensive sampling design with multiple surveys before new moon each month, in addition with a calibration with the lunar calendar.

Limitations of the study

Our findings together with a previous study (Golbuu and Friedlander 2011) show that the present management strategies are effective at protecting grouper's species in Palau. Despite these encouraging findings, additional conclusions were restricted due to potential limitations of the study design.

Firstly, the reference sites used in this study, even if they formally harbored spawning aggregations, have differences in their environment characteristics, which may hinder the testing of protection. Denges channel is located on the east coast in contrast to Ngerumekaol which is located on the west coast. Denges was also impacted by typhoon Bopha in 2012, which damaged the benthic structure and may have affected the viability of the site to hold fish aggregation. Ngeremlengui channel also displays a different benthic community compared to ECA. Despite these environmental differences, the evidence of historical aggregations at these sites (Sadovy 2007) suggests that if grouper population were recovering in the absence of protection, these sites would be the most likely places to observer any increase in abundances.

Secondly, although the scope of our study was to look at relative change in abundance and biomass of groupers at spawning sites, the size of the site where the aggregations take place should have been taken into account into the sampling design. Increasing the coverage of the surveys in larger sites would have been beneficial as there would have been less spatial restriction on the precise locations of the aggregation. NSA and Denges sites are small areas so five 50 m transects seem to have been sufficient to capture most of the aggregation. However, Ngeremlengui and ECA are much larger sites, therefore, doubling additional transects should be considered to have a better picture of the whole aggregation.

Thirdly, aggregation sites were surveyed only once every month. Johannes et al. (1999) advised to monitor at least 2-3 days per month around the spawning peak to capture any variability in timing of aggregation formation. Whilst this may capture a better representation of the peak size of each aggregation, the logistical constraints of visiting multiple spatial-isolated sites limited our survey schedule to one survey per site per month

Finally, throughout the timeframe of these surveys, there were a total of six fish surveyors. Despite the size-calibration training effort using fish models, the bias generated by numerous observers was inevitable and made it difficult to formally determine any shifts in size frequency distribution. Accurate information on fish sizes is crucial information for assessing fish population viability. From our data, we observed that our estimates of mean fish size at FSAs was actually lower than observed size of sexual maturity in another Micronesian island, Pohnpei (e.g. *E. polyphekadion*; Rhodes et al. 2011). Whether this observation is due to geographical differences or fishing pressure remains to be studied, but this information might be useful for future fisheries management.

General conclusion and management recommendations

Despite these limitations, our current study highlights that the implementation of multiple management initiatives (MPAs and seasonal closures) have resulted in overall positive responses for grouper populations in Palau. Protection seems to be effective especially for larger groupers, *E. fuscoguttatus*. Protection have been shown to lead to a normalization of male:female sex ratios, hence improving the output of fertilized eggs during spawning (Gruss and Robinson 2015). Regarding *P. areolatus,* further research is needed to better understand the spawning patterns of the species in Palau, to assess the effects of the current management regimes and to better fit management regulations to the ecological behavior of this species. From our data, we did not observe any increase in groupers at non-protected sites which implies that the seasonal closure is not a sufficient regulation for the local fisheries. Therefore, further fisheries measures should be considered. A recent fisheries study in Palau demonstrated that *P. areolatus* caught by fishermen were too small, suggesting a spawning potential lower than 10% (Prince et al. 2015) Combining these findings, we can speculate that very often groupers caught by local reef fisheries are too small and not mature enough to sustainably replenish the local populations. Therefore, the implementation of minimum fish size year-round should be considered in future policy-making, to increase the spawning ability of groupers in Palau and harvest them sustainably.

Acknowledgment

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Appendix 1: GPS Coordinates of survey sites

Position of the first transect at 10m depth except for Ebiil CA where it starts at 20m depth

Ngerumekaol_SA	07 17.117'N	134 14.901'E
Denges_channel_REF	07 07.124'N	134 22.615'E
Ebiil_CA	07 46.396'N	134 34.169'E
Ngaremlengui_channel_REF	07 32.408'N	134 27.689'E