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Coral Reef Fish Spawning Periodicity and Habitat in New Caledonia: a multi-faceted approach in a data-deficient environment

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Abstract An Environmental Impact Assessment (EIA) for a proposed mining project on the west coast of Northern Province, New Caledonia, required an understanding of coral reef fish spawning/aggregation periodicity and habitat utilisation in New Caledonia in order to describe and mitigate the potential impacts of the development. A study was undertaken that encompassed literature review, interpretation of oceanographic data, analysis of gonad index data spanning some 18 years, analysis of commercial fisheries production data, interpretation of sales data from the Nouméa fish market, interviews with commercial and subsistence fishermen and personal communication with researchers at University of New Caledonia regarding unpublished records and observations. Literature review highlighted the variation in spawning periodicity that occurs on a spatial scale of reefs to ocean basins. Gonad index data indicated that spawning of key coral reef fish species is concentrated in the spring and summer months in New Caledonia. Commercial fisheries production increased in spring and summer. The increase in production was not due to heightened fishing effort and was presumably as a result of increased catchability of fishes in spawning aggregations. Market sales (measured in kilograms of fish sold) were highest between September and December. Interviews with village fishers also indicated spring–summer spawning of some species. Oceanographic data supported spawning periodicity and habitat inferred from the other indicators. Oceanographic data also supported the possibility of a large-scale northerly spawning migration up the west coast of New Caledonia for at least some species.

Keywords reef fish spawning, aggregation, New Caledonia, barrier reef, mining, impact.

Introduction

While most temperate fishes have a well-defined breeding season that is regulated by hormonal changes and a variety of environmental cues such as temperature and photoperiod (Scott 1979; Lam 1983; Bye 1984; Stacey 1984), tropical species generally have a protracted breeding season and the specific cues regulating spawning periodicity are not well known, although photoperiod, sea temperature and currents are often quoted as the most influential (Munro et al. 1973; Thresher 1984; Walsh 1987).

Although the timing of spawning can occur randomly in tropical environments, spawning is more commonly synchronised within a population (Johannes 1978; Colin and Clavijo 1988). Many coral reef species spawn on daily or lunar cycles (Thresher 1984; Gladstone and Westoby 1988), but even these species may vary in the timing of spawning, both within populations (Ochi 1985) and between populations (Foster 1987; Robertson et al. 1990). Spawning periodicity in tropical reef fishes, therefore, is species- and site-specific.

Recently, collaborative databases such as FishBase (Froese and Pauly 2005) and the Society for the Conservation of Reef Fish Aggregations (SCRFA) database and Manual for the Study and Conservation of Reef Fish Spawning Aggregations (Colin et al. 2003) have contributed much to the state of knowledge of the location and periodicity of spawning aggregations. Further, some coral reef fish species that are known to form spawning aggregations have received attention in the literature from a fisheries management perspective because recreational and commercial fishermen target these aggregations to maximise catches. Notwithstanding this, there remains a paucity of data available on spawning aggregations for many remote locations.

Fishes that are best known to travel sometimes large distances from their home reefs to form spawning aggregations are groupers (Serranidae),

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snapper (Lutjanidae), jacks (Carangidae) and surgeonfish (Acanthuridae) (Domeier and Colin 1997). Spawning aggregations, for some species, are believed to represent all of the reproductive effort for a year (Shapiro et al. 1993). Therefore, impacts to spawning aggregations of some species may be potentially detrimental to the breeding success of the population on a regional scale.

The present study was undertaken as part of an Environmental Impact Assessment (EIA) for a proposed nickel mining operation in New Caledonia. Located in the Southwest Pacific, New Caledonia is surrounded by the world's second largest barrier reef system (Fig. 1).

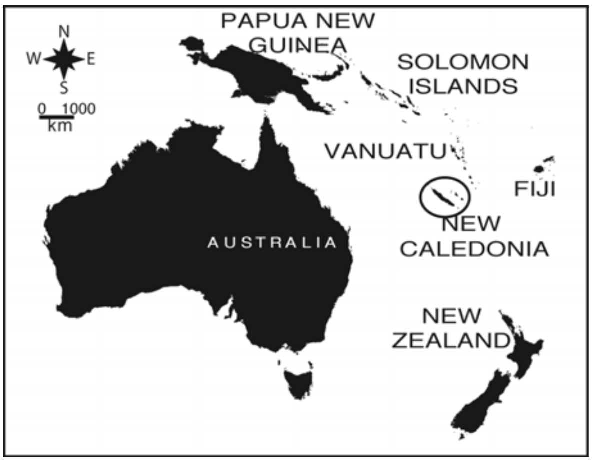

Fig. 1. Location of New Caledonia.

The proposed development of a shipping wharf associated with the project on the west coast of the Northern Province of New Caledonia, would require dredging of the seafloor to achieve sufficient water depths for ships to enter the lagoon, turn and exit (Fig. 2). The issue of potential impacts to spawning/aggregating fishes and survival of eggs and larvae arising from the generation of turbidity plumes and elevation of sedimentation rates from dredging of mud, sand, rock and coral outcrops was the focus of an EIA. Knowledge of coral reef fish spawning periodicity and habitat in northwestern New Caledonia was required to inform the EIA and to comply with international best practice environmental management of dredging guidelines.

Reef fish spawning periodicity and habitat in New Caledonia is not well documented. Time and money constraints precluded embarking on a dedicated research effort and so an assessment of a number of first-order indicators was carried out to elucidate the timing of aggregation and spawning by coral reef species in northwest New Caledonia and the habitats used for spawning. This study, conducted in 2001, prior to the publishing of Colin et al. (2003), represents an applied scenario where decision inputs into an impact assessment were required in the absence of hard data.

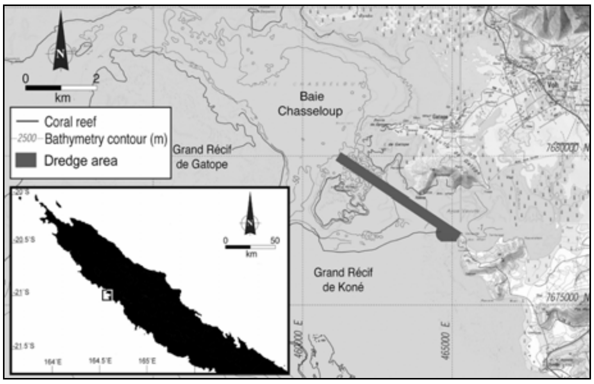

Fig. 2. Location of proposed dredging area.

The first-order indicators that were available and were used in this study reflect the philosophy of the Manual for the Study and Conservation of Reef Fish Spawning Aggregations (Colin et al. 2003), while also including other specific inputs that were available at the study site. The indicators used in this study may be useful for other locations where a rapid appraisal of reef fish spawning aggregations is required, particularly with respect to coastal development projects where inputs from coastal engineering studies may be available.

Materials and Methods

Literature and Data Review

When reviewing literature, most weight was given to studies concerning similar species to those in New Caledonia and geographically, to studies concerning barrier reef systems in the southern hemisphere in the tropical Pacific Ocean. Studies in other ocean basins, other reef types, or in the northern hemisphere, while still useful, were viewed to be of less relevance to New Caledonia.

Bathymetric and Oceanographic Indicators

An oceanographic modeling investigation was carried out as part of the detailed engineering design of the wharf and dredging program. The model used by the project engineers was the Delft 3D numerical model, developed and maintained by Delft Hydraulic. The model solves the Reynolds average Navier Stokes equation for turbulent fluid motion and in 3 dimensions. The model was validated and calibrated with measurements of tides, waves, temperature, winds and currents (Fig. 3). Deployment of the various oceanographic instruments was intermittent from 2000 to 2003 and spanned weak to moderate El Niña conditions to moderate El Niño conditions. No analysis of the influence of the El Niño-Southern Oscillation (ENSO) index on oceanographic conditions was made.

In addition, a detailed bathymetric survey was undertaken and sea surface temperature (SST) images of New Caledonia were also acquired to complement oceanographic data. Detailed methods of bathymetric, oceanographic and SST data acquisition are not described here as these studies were not specific to the fish spawning study. However, outputs from these components and the modeling exercise were analysed and interpreted in this study.

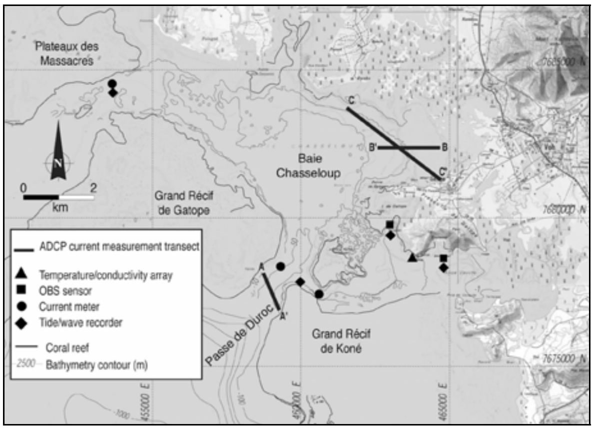

Fig. 3. Location of oceanographic instruments and activities. An additional ADCP current meter was deployed to the south of the study area in approximately 150 m water depth.

Gonad Index Data

New Caledonia's Institut de Recherche pour le Développement (IRD) conducted experimental fish sampling surveys in northern and southern New Caledonia from 1984 to 2001. Sampling was sporadic but included most months in most years. Experimental fishing included the use of demersal trawls, gill nets, hand-line and long-line. During each survey, dissections were carried out on a sub-sample of the total fish catch and gonad index was recorded for male and female specimens. The gonad index (GI) ascribed to dissected individuals was based on a qualitative and standardised method for assessing gonad developmental stage (Tab. 1).

The gonad index data set comprised 28,719 individuals from approximately 220 species. For this study, we were interested in the months of potential spawning and aggregating rather than the absolute time of spawning.

Tab. 1. Qualitative gonad index scale.

GI	Description
1	Immature
2	Early developing
3	Developing
4	Late developing
5	Ripe/Running Ripe
6	Spent

At least some aggregating species are known to commence aggregations (or at least spawning migrations) days or weeks prior to the time of actual spawning (Rhodes and Sadovy 2002; Domier and Colin 1997). As this study was concerned with potential impacts to aggregating fishes and not only the act of spawning, GI greater than or equal to 4 (i.e., includes GI = 4, 5 or 6) were considered to be in 'spawning condition' (and operationally 'aggregating condition'), with the assumption that fishes in this category may be yet to spawn for days to weeks and, by the same token, may have already spawned.

To reduce the influence of variable monthly catch rates, the percentage of individuals with GI ≥ 4 in each month (for all years combined) was examined instead of absolute numbers. Only GI data from females were used in the analysis. Further, only species that had 50 or more specimens dissected were used in the analysis. Data for genus *Lethrinus*, *Lutjanus* and *Upeneus* are presented here.

Commercial Fisheries Production

The Northern Province Fisheries Department of New Caledonia issues commercial licenses to fishermen operating in Northern Province. As a condition of the license, fishermen report catches (weight by species, genus or family) on a monthly basis and catch data from 1993 to 2000 was available for this study. Oceanic pelagic species and deep-slope species were removed from the database and mean monthly production (kg) was calculated for coastal reef fishes only. No catch per unit effort data were available in the fisheries statistics. However, to gain an indication of fishing effort, the number of fishermen reporting catches (which was assumed to equal the number of fishermen operating each month) was examined for each month.

Clearly, the reliability of this data is a function of the reliability of commercial fisher reporting which is unknown. This is an artefact of all fisherman-reported catch statistics but considering the data spanned some 7 years and was as much as the Government fisheries authority could provide, it was deemed valuable as an additional first-order indicator to input to this study.

Nouméa Market Sales Data

In 2004, data was obtained on the weight of fish sold each month by 12 out of the 23 fish retailers in Nouméa market. Fish sold were not always identified to species or genus level.

Local Fisher Knowledge and Other Research

Researchers from the University of New Caledonia and IRD have a long history of fish studies, particularly in the south of the country. While most of data remains unpublished, information was obtained from senior researchers based on their observations and knowledge of the region.

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A subsistence/small scale commercial fisherman at a village in the study area (Voh) and three commercial fishermen at Nouméa fish market were interviewed about coral reef fish spawning periodicity and habitat. These information sources provided further first-order indicators that were available in the absence of hard data and were used to support this study. During interviews and correspondence, 'aggregation' was operationally defined as a transient, noticeable increase in fish density. The recommended definition outlined in Colin et al (2003) was unable to be followed with respect to verification of spawning.

Results

Literature Review

Periodicity

Histological examination of gonads of *Plectropomus leopardus* and *Plectropomus maculatus* showed that these species spawn multiple times during September through November of the Great Barrier Reef (GBR) (Ferreira 1993). On the northern GBR, spawning aggregations of *P. leopardus* were found to begin increasing in numbers on the full moon in October, with numbers peaking over the new moon, and then decreasing rapidly over the first quarter (Samoilys and Squire 1994), although prolonged annual spawning has been recorded from August to December (Zeller 1998; Samoilys 1997). Pronounced lunar periodicity of spawning has been observed in other serranids (Johannes 1978; Thresher 1984; Colin et al. 1987; Colin 1992) and is common in other species of pelagic spawners that migrate to spawn (Samoilys 1997).

Spawning aggregations of *Plectropomus areolatus* have been reported in the Solomon Islands from February to June, peaking from March to May (Domeier and Colin 1997). The spawning period of *P. aereolatu* in the Solomon Islands is later than that observed for *P. leopardus* on the GBR.

In Micronesia, *Epinephelus polyphekadion* appears to spawn between February and April, concentrated within one to two evenings, one to two days prior to the full moon between dusk and dawn (Rhodes and Sadovy 2002). *E. polyphekadion* migrations in Micronesia are characterized by the arrival of males 10–12 days prior to spawning, with females arriving 6–7 days later. The differential movement of males and females into the aggregating/spawning site has also been described for this species in the Solomon Islands (Johannes 1989) and for *P. areolatus* in Palau (Johannes et al. 1999) and *P. leopardus* on the GBR (Samoilys 1997). Rhodes and Sadovy's (2002) study of the spawning of *E. polyphekadion* in the Indo-Pacific region illustrates the geographic variability in spawning periodicity in reef fishes (Tab. 2).

Observations of the spawning of *Pseudobalistes flavimarginatus* (Balistidae) on the GBR indicate that the species spawns between November and March, with mating occurring two to five days before the new moon and full moon (i.e., twice each month). (Gladstone 1994). A tidal cycle was also evident in the spawning of *P. flavimarginatus*, that lays eggs in demersal nests, with mating occurring 1–5 days before the spring tides, on days when high tide occurred around sunset (Gladstone 1994).

The influence of local-scale variation in environmental cues on spawning periodicity has been demonstrated in Hawaii. Spawning of *Chaetodon multicinctus* (Chaetodontidae), *Centropyge potteri* (Pomacanthidae), *Ctenochaetus strigosus* and *Zebrasoma flavescens* (both Acanthuridae) occurred from January to July with reproduction peaking at times when wind velocities are highest and mesoscale eddies (that have the potential for the greatest entrainment and retention of larvae and food resources) are most likely to occur (Lobel 1989). Also in Hawaii, the spawning of *Dascyllus albisella* from May through August (Stevenson 1963) is triggered by an increase in water temperature (of approximately 0.4˚C). Similarly, a rapid decrease in water temperature (1.7 to 2.8˚C drop) results in a rapid termination of spawning (Danilowicz 1995).

Review of literature concerning reef fish spawning periodicity in the tropical western Pacific Ocean revealed that there was very little information available for New Caledonia. Further, literature demonstrated that, where data were available, there was significant site-specificity in spawning periodicity for many reef species, driven by variability in the environmental cues for spawning on the scale of reefs to ocean basins. There was limited ability, therefore, to geographically extrapolate from published studies to infer spawning periodicity in New Caledonia.

Habitat

In Pohnpei, Micronesia, *E. polyphekadion* is known to travel distances of 10 km or more to spawn and has been found to aggregate in 30 to 50 m water depth on the outer reef slope (Rhodes and Savoy 2002). Fish were reported to be consistently concentrated around low-relief corals and sand patches, where males defended territories of 1 to 2 m^2.

P. leopardus has been found to migrate between 200 m and 5.2 km between home-range and spawning aggregation sites on the GBR (Zeller 1998). At Lizard Island, on the GBR, actual spawning aggregation sites of *P. leopardus* were located on the outer slope of the fringing reef, typically on the most exposed side of the island.

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Tab. 2. Summary of seasonal and lunar variation in spawning of *E. polyphekadion*

Location	**Month**	**Season**	**Lunar Cycle**
Kuwait	Apr-Jul	Mid spring–summer	New Moon
Saudi Arabia	May-Jun	Late spring–summer	New Moon
Palau	Jun-Aug	Summer	New Moon
Marshall Islands	Dec-Jan	Summer	na
Pohnpei	Feb-Apr	Late summer	New Moon
Solomon Islands	Oct-Jan/Feb-Jun	Mid spring–summer–early winter	na
French Polynesia	March	Early spring	na
Cook Islands	Apr-Jun	Autumn–winter	na
New Caledonia*	Nov-Jan	Late spring–summer	Full Moon
New Caledonia**	Oct-Feb	Mid spring–summer	na

Modified from Rhodes and Sadovy (2002). na = not available. * pers obs. (MK), cited in Rhodes and Sadovy (2002). ** Loubens (1980).

The location of spawning aggregation sites at Lizard Island corresponds with prominent exposure to currents (Zeller pers. comm.). In the northern GBR, *P. leopardus* utilised the same aggregation site each year and the size of these aggregation sites ranged from 1700 m^2 to 3200 m^2 (Samoilys 1997).

Gladstone (1994) identified a *P. flavimarginatus,* 'mating ground' in a natural gutter on the GBR that was 250 m long, 75 m wide and had a depth at high tide of 8 m. The substratum at the site consisted of sand-coral rubble and courtship, spawning and parental egg care all took place at this site.

Spatial differences in current flow along a coastline can influence spawning sites and may be an important habitat factor for pelagic, broadcast spawners that have little affinity to a substrate type. In South Africa, for example, movement of spawning adults of a number of species in summer is upstream (north) of a large nursery site and upwelling area (Hutchings et al. 2002). In summer, there is a strong downstream (south) current flow and the northerly (upstream) migration is understood to offset the current flow and maximize retention of larvae and eggs close to the coastline near a known nursery area. Further, in winter/spring, when the downstream current flow is not as evident, spawning takes place much closer to the nursery ground.

Literature concerning reef fish spawning habitat was scarce, but indicated that physical oceanographic parameters, in particular water temperature and currents, were likely to be more important than benthic habitat parameters to pelagic broadcast spawners (Samoilys 1997; Danilowicz 1995; Gladstone 1994; Lobel 1989; Zeller 1998). Records of the utilisation of benthic habitats and features in the literature are generally site-specific, sometimes of the scale of specific reef features such as coral bommies. As with spawning periodicity, it was difficult to geographically extrapolate from other studies to infer spawning habitat in New Caledonia. However, information valuable to the assessment of dredging impacts was obtained.

Bathymetric and Oceanographic Indicators

Examination of detailed bathymetric data allowed the identification of potential spawning aggregation features such as prominent points, pinnacles and gutters. The structurally complex New Caledonian barrier reef and lagoon system creates complex hydrodynamic processes that are likely to be important drivers influencing spawning habitat. Hydrodynamic processes of the lagoon were modeled based on acquired oceanographic and bathymetric data. The modeling of a typical ebb tide demonstrated strong current flows through channels in the barrier reef and near tidally-inundated reef plateau. This hydrodynamic data, in combination with the bathymetric data, allowed potential aggregation and spawning sites to be identified (Fig. 4).

ADCP current profiling data collected offshore of the barrier reef indicated that surface water flows along the west coast of New Caledonia are predominantly southerly and that current velocities are highest during the spring–summer period (NSR 2002). Further, SST images during the spring-summer period indicate seasonal warming of waters, with a temperature of approximately 28˚C in the far northwest region and a distinct cold-water upwelling feature, with a temperature of approximately 24˚C, in the southwest (Fig. 5).

As will be discussed in more detail below, this large-scale oceanographic indicator supports observations and hypotheses of a large-scale northerly spawning migration up the west coast of New Caledonia for some species. This migrations may act to firstly offset the predominately southerly current flow, secondly, place aggregations in warmer water providing a possible temperature cue for spawning, and thirdly, promote the retention of larvae in the region of an upwelling area in the southwest. Such upwelling areas are often associated with high nutrient levels and promote the retention of larvae and have been associated with 'nursery' areas (Hutchings et al. 2002).

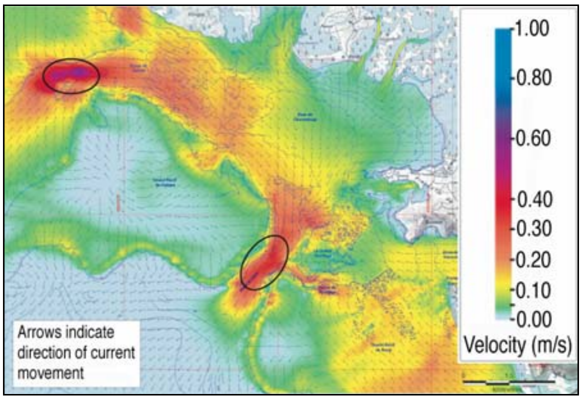

Fig. 4. Ebb tide current flows as estimated by hydrodynamic modeling. Potential aggregation sites circled.

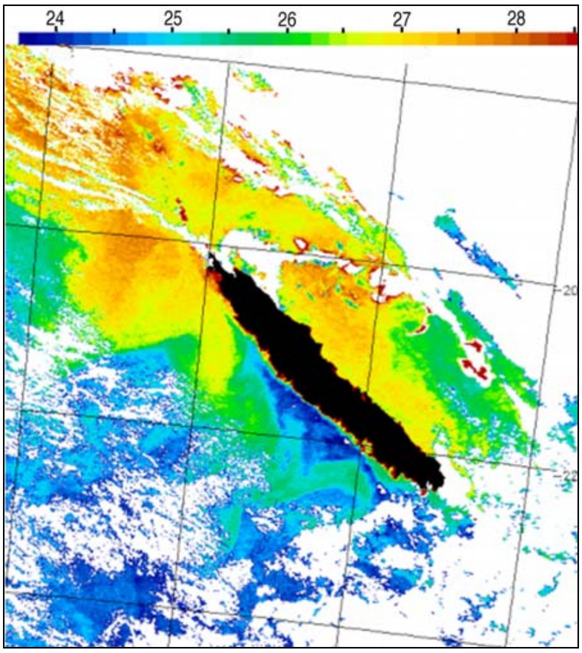

Fig. 5. SST image of New Caledonia showing distinct coastal upwelling region in the southwest and warm water in the northwest. Scale shows temperature (˚C). Source: CSIRO Marine Research, Hobart, 2001.

Gonad Index Data

Genus *Lethrinus*

There was a general trend for an increase in the proportion of lethrinids with GI ≥ 4 (in spawning condition) from August to November (Fig. 6). A high proportion of *Lethrinus atkinsoni* were also in spawning condition in January. A high proportion of *Lethrinus rubrioperculatus* are in spawning condition in January, February and March. While May to July appears to be a time of reduced gonad maturation in most species, *L. genivittatus and L. rubrioperculatus* have a peak in the proportion of individuals in spawning condition in June.

Genus *Lutjanus*

The highest proportion of female lutjanids with gonads in spawning condition occurred from September to December (Fig. 7). *L. vittus* displays a second peak in gonad development in February, and a smaller peak in June.

Genus *Upeneus*

U. vittatus and *U. moluccensis* also showed peaks in the latter part of the year, extending into January for *U. vittatus* (Fig. 8). However peaks in the proportion of females with GI ≥ 4 also in June and July for some species, indicating a possible mid-year spawning event.

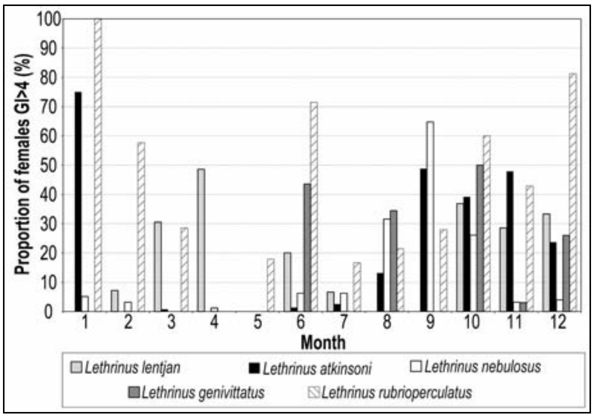

Fig. 6. Monthly proportion of female *Lethrinus* spp. with GI ≥ 4.

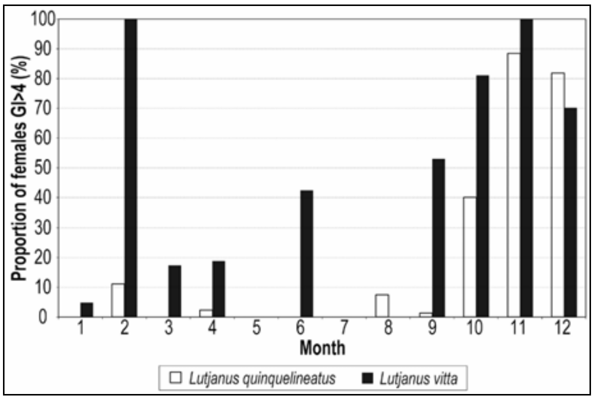

Fig. 7. Monthly proportion of female *Lutjanus* spp. with GI ≥ 4.

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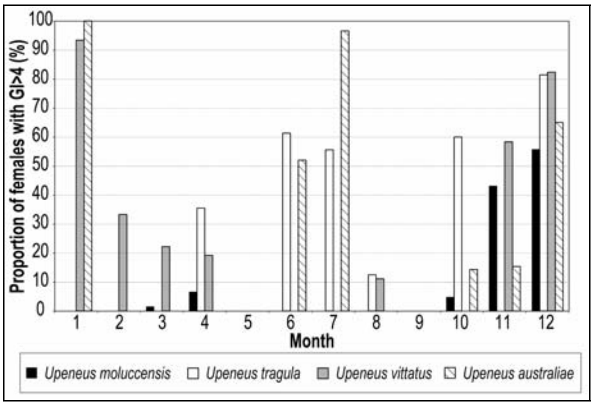

Fig. 8. Monthly proportion of female *Upeneus* spp. with GI ≥ 4.

Commercial Fisheries Production

Examination of the monthly pattern of the number of fishermen reporting catches from 1993 to 2000 revealed that commercial fishing effort (the number of fishermen reporting to Northern Province Fisheries Department) was significantly elevated in December compared with other months. This was due to the fact that in 1993 and 1994, fish catches were only recorded for the month of December. The over-representation of the month of December in the data set was corrected by removing 1993 and 1994 data. The final data set therefore spanned from 1995 to 2000.

Average monthly production peaked in December for most species examined (*Lethrinus nebulosus*, other lethrinids, parrotfishes (Scaridae), rabbitfishes (*Siganus* sp.) and *Naso unicornis*) (Fig. 9). Production for mullets (Mugilidae) was highest in the early part of the year (January to March/April), with another peak from October to December.

Production was not correlated to fishing effort (measured as ‘number of fishermen reporting catches) (Fig. 10) (r^2<0.3 for all groups in Fig. 9). Elevated production during the summer months may be a result of increased catchability of some species due to aggregating behaviour and the periodicity of production peaks is in good agreement with the periodicity in GI data and the inferences from literature and oceanographic data. It was not possible to analyse the correlation between GI periodicity and production because these data were from different sources and there was insufficient overlap in species between the data sets (i.e. there was no production data available for the species that had the most useful GI data).

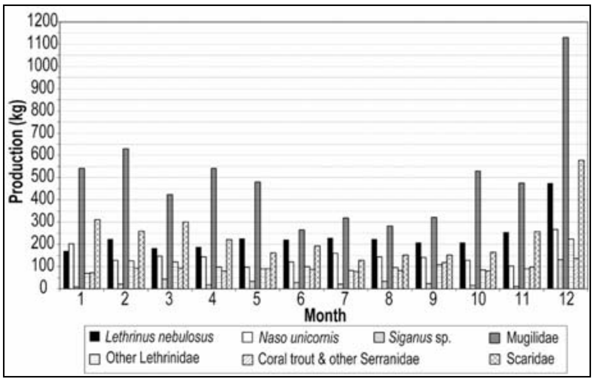

Fig. 9. Mean monthly production for selected species in the Northern Province Fishery 1995 to 2001.

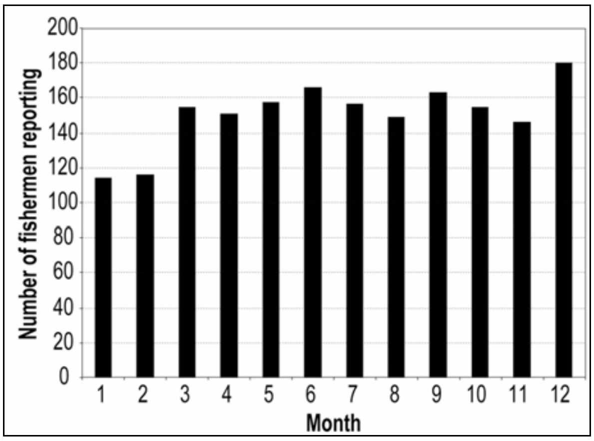

Fig. 10. Mean monthly number of fishermen reporting catches (a proxy for fishing effort) from 1995 to 2001.

Nouméa Market Sales Data

Total monthly sales by weight of selected lethrinids for 2004 shows a bi-modal pattern that reflects that of GI data and fisheries production data (Fig. 11). Sales of *Epinephelus* spp. increased from October to December. Sales of *Lutjanus adetti* peaked in October and remained relatively high in November and December while other sales of other lutjanids showed little variation throughout the year.

Additional indicators arose from the Nouméa market study. Firstly, female gonads of *Epinephelus coioides* and *E. malabaricus* are sold separately only during the October to December period (J. Mounier, pers. comm.). Further, the gonads of mullet (Mugilidae) are sold towards the end of the year. These mullets are reported to be caught close to mangroves at this time. However, interestingly, commercial fishing for mullets is prohibited between 1st April and 31st July, suggesting the possibility of an additional mid-year spawning period for these fish. Commercial fishing for rabbitfishes (Siganidae) is prohibited between 1st September and 31st January, again presumably to protect spawning fishes (J. Mounier, pers. comm.).

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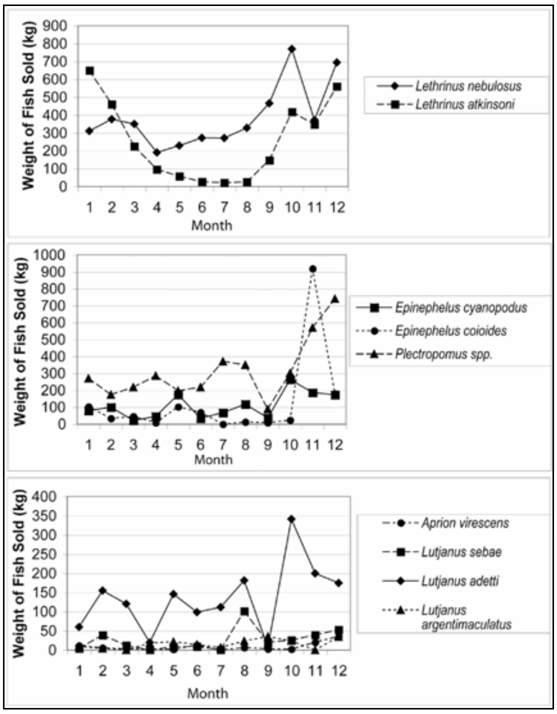

Fig. 11. Monthly sales data for 2004. **A**, Lethrinidae. **B**, Serranidae **C**, Lutjanidae.

Local Fisher Knowledge and Other Research

Information from unpublished research and observations in New Caledonia by scientists and observations and results of fishermen interviews generally supported data from other indicators and this study provided an opportunity to centralise and summarise this data (Tab. 3).

Passes (channels in the barrier reef) in southern New Caledonia, in particular Dumbea Pass in the southwest, are known to be important spawning aggregation sites. Indeed, local regulations prohibit fishing in part of Dumbea Pass during aggregation periods (C. Chauvet, pers. comm.). Research efforts in New Caledonia have focussed on the southern parts of the country and therefore records of spawning aggregations for the northern parts of the country are scarce. However, the reef morphology and habitats in the northern and southern parts of New Caledonia are similar and similarities in spawning periodicity and aggregation sites are expected.

Village fishermen reported a large-scale northerly migration of some species of rabbitfish (Siganidae) and surgeonfish (Acanthuridae) during spring–summer months in interviews that were carried out in 2001. More recently, a large-scale northerly migration was hypothesised as a possible explanation for season patterns of abundance of five species of acanthurids on northern reefs (Coll 2003). As mentioned above, oceanographic indicators provide a possible explanation and driving mechanism for such a migration.

Discussion

By analysing data from various first-order indicators, we were able to elucidate spawning periodicity and habitat of coral reef fishes in New Caledonia and provide suitable input to the EIA process in the absence of hard data. Literature review highlighted the difficulties in extrapolating spawning periodicity on a geographic basis at the spatial scale of ocean basins and hemispheres to reef features. Literature review also highlighted the paucity of information available on spawning habitat but uncovered information that was useful for impact assessment purposes. For example, cues for aggregating and spawning of pelagic broadcast spawners are likely to be primarily physical oceanographic parameters such as water temperature, photoperiod, tides and currents (Samoilys 1997; Danilowicz 1995; Gladstone 1994; Lobel 1989; Zeller 1998) and as such are susceptible to water-column impacts. Notwithstanding this, pelagic broadcast spawners have been known to aggregate around specific benthic features, which is of relevance to the assessment of impacts of coastal dredging or other development. Fishes that lay eggs in demersal nests obviously have a closer association with the substrate and would be more susceptible to benthic habitat impacts.

Gonad index data suggests that spawning of many species analysed (for example, *Diagramma pictus*, *Epinephelus maculatus*, *Lethrinus* spp., *Lutjanus* spp., *Nemipterus furcosus*, *Pomasdasys argenteus*, and *Upeneus* spp.) occurs from September to March, with indications of a possible mid-year spawning event for some species in June–July. Peaks in monthly fisheries production matched monthly peaks in GI for many species and peaks in fisheries production were not related to peaks in fishing effort. It is hypothesized that production increased due to fishermen accessing aggregations. Peaks in fisheries production (data from 1995 to 2001) were reflected in market sales data (data from 2004).

Reports of a large-scale northerly migration on west coast of New Caledonia are supported by oceanographic data that demonstrate strong southerly currents, warming of northern waters and distinct seasonal upwelling in the southern part of the west coast in spring–summer. Northerly migration would place aggregations in higher-temperature waters that may trigger spawning while also promoting the southerly transport of larvae to a distinct upwelling feature. Upwelling zones are often associated with high nutrient waters and have been found to be ‘nursery’ areas and may minimize the loss of larvae to offshore waters due to their eddying effect.

Tab. 3. Summary of research records and observations of fish aggregations and spawning in New Caledonia. A = Aggregation only observed, S = Aggregation and spawning observed, M = Migration observed (S) = Southern Province, (N) = Northern Province. Sources: C. Chauvet, pers. comm., E. Clua, pers.comm., C. Coll, pers. comm. * = villager interview (n=1), ** = commercial fishermen interviews (n=3). Others = University of New Caledonia researcher records.

Family	**Species**	**Obs**	**Period**	**Location**	**Habitat**
Serranidae	*Plectropomous leopardus*	A	Nov-Dec Oct-Nov, Males arrive Sep	Ouano and Uitoe Pass (S) Dumbea Pass (S) - irregular	Inner-reef side of pass
	Plectropomous laevis	A	Oct-Nov, Males arrive Sep	Dumbea Pass (S)	
	Cromileptes altilevis	A	Aug-Sep	Dumbea Pass (S)	
	Epinephelus malabaricus	A/S	Sep-Dec Nov-Dec ?	Dumbea Pass (S) Prony Bay (S) Bay Maa (S)	 Patch reefs Coral bommies
	Epinephelus coioides	A/S	Nov-Dec	Prony Bay (S)	Pinnacle and patch reefs
	Epinephelus fuscoguttatus	A	Oct-Dec	Dumbea Pass (S)	
	Epinephelus cyanopodus	A/S ?	Oct-Dec ?	Dumbea Pass (S) Southern Islands including Mato Is.	 Sand pacthes
	Epinephelus polyphekadion	A/S	Nov-Dec	Dumbea Pass (S)	
	Epinephelus caeruleopunctatus	A		Dumbea Pass (S)	
	Epinephelus tauvina	A		Dumbea Pass (S)	
Kyphosidae	*Kyphosus spp.*	A	Sep-Mar	Dumbea Pass (S)	
Lutjanidae	*Macolor niger*	A	Sep-Mar	Dumbea Pass (S)	
Holocentridae	*Myripristis spp.*	A	?	Dumbea Pass (S)	Outer-reef
Haemulidae	*Plectrorhincus lineatus*	A	Sep-Mar	Dumbea Pass (S)	
	Plectrorhincus albovittatus	A	Arrive ? Depart Feb-Mar	Dumbea Pass (S)	
Siganidae	*Siganus lineatus*	S	Full moon Nov-Dec	Various	Close to mangrove channels
	Siganus argenteus	S	Sep-Mar**		
	Siganus fuscescens	S	Full moon Nov-Dec	Various	
Mugilidae	Mullet species	S	Sep-Oct* Dec-Feb**		Mangrove
Labridae	*Bodianus perditio*	S	Mar-Apr**		
Lethrinidae	*Lethrinus nebulosus*	S	Jul-Aug* All Year**	Koné (N)	Inner reef plateau,
Acanthuridae	*Naso unicornis*	A S	Apr-May Jul-Aug*	Koné (N)	Barrier reef
	Acanthurus blochiii	M	Apr-May	Koné (N)	Barrier reef
	Acanthurus nigricauda	M	Apr-May	Koné (N)	Barrier reef
	Acanthurus xanthopterus	M	Apr-May	Koné (N)	Barrier reef
	Acanthurus dussumieri	M	Apr-May	Koné (N)	Barrier reef

Given the complex reef morphology and hydrology of the New Caledonian barrier reef system, spawning habitats are likely to be site-specific and require investigation. Research in southern New Caledonia has identified specific spawning aggregation sites while data for Northern Province is very limited.

Studies of spawning aggregations worldwide are plagued by the lack of verification of spawning activity and this is true for this study. However, the approach taken for this study may be useful in other remote locations where detailed data is deficient but first-order indicators are available, particularly in the situation where coastal engineering inputs to a development project such as modeling, bathymetry and oceanography may be available to support biological data.

At the time of writing, the EIA had been successfully completed and the mining project (including the associated dredging operation) was progressing through the environmental and financial approvals process.

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