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The conservation status of Niugini black bass: a world-renowned sport fish with an uncertain future

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Abstract The Niugini black bass, *Lutjanus goldiei* Bloch, is an estuarine and freshwater fish species endemic to New Guinea and the surrounding islands. It is the focus of a growing sport fishing industry that has the potential to provide long-standing benefits to local people. Plantation agriculture, mining and logging are expanding in many catchments where *L. goldiei* is found, creating the potential for these industries to impact on *L. goldiei* and the environments it relies on. Understanding of the current status of the species, including its biology, ecology and distribution, is essential for its sustainable management. However, very little is known about the species. Here, the published literature, unpublished data and interviews with anglers and fisheries officers were used to draw together existing knowledge, assess the current conservation status, make a preliminary analysis of threats and identify key areas for research that will support the sustainable development of the *L. goldiei* sport fishing industry while fostering positive conservation outcomes.

KEYWORDS: conservation, estuary, fishing, freshwater, Lutjanid, tourism.

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Introduction

As a large, hard-fighting estuarine and freshwater sport fish species, Niugini black bass, *Lutjanus goldiei* Bloch, has been identified as a valuable target for the next wave of tourism development in Papua New Guinea (PNG). Locally based sport fisheries have the potential to provide stable alternative livelihoods and food security for PNG's coastal villages and, as a result, generate significant environmental benefits by creating incentives to conserve *L. goldiei* and their key habitats. While experience from other parts of the world has shown that remote indigenous communities can derive livelihood benefits from sport fisheries (Wood *et al.* 2013), potential limitations and constraints need to be managed, including lack of training in operating a sport fishing business, lack of experience in business commercialisation, fluctuating tourism markets, aligning with culture-specific social norms and managing intercommunity friction and territoriality. Concrete socio-economic goals need to be identified, and site-specific market analysis and research on the linkages between goals, community capacity and incentives conducted. At the same time, the ecology and biology of the fish and the fishery need to be understood so that the resources on which commercial success depends can be managed sustainably.

Flagship species, such as the bird of paradise, have proved powerful icons to drive terrestrial conservation in PNG (J. Kasu, pers. comm.), and sport fish such as tarpon, *Megalops atlanticus* Val., and bonefish, *Albula vulpes* (L.), have served that role in the Caribbean and Central American coastal ecosystems (Adams *et al.* 2014). However, up until now, there has been no similarly iconic aquatic species in the Pacific Islands. *Lutjanus goldiei* has been suggested as a flagship species for aquatic conservation efforts in PNG (Allen 2004), because it enjoys great popularity among the international angling community, where it is considered one of the world's toughest sport fish (Kreh 2012). This popularity means that raising international awareness of *L. goldiei* and the development of locally based sport fisheries has the potential to generate significant environmental benefits by creating incentives to conserve key habitats (Cowx *et al.* 2010; Sheaves 2013) while supporting diversification of rural livelihoods (Wood *et al.* 2013).

There has been little action to advance Allen's (2004) idea of promoting *L. goldiei* as a flagship species for aquatic conservation in PNG. One major impediment has been the almost complete lack of the published literature on the species, with a large proportion of what is available amounting to no more than mentions in species lists in technical reports. This paucity of information severely hampers any attempts to understand the biology of *L. goldiei*, to determine its conservation status or threats to the key habitats and biological resources on which it depends. Papua New Guinea's aquatic systems have been the subject of many ecological studies in recent years, many of which are unpublished, but often data rich. In addition, anglers have targeted *L. goldiei* for over 50 years, and there is currently a small but growing sport fishing industry (Wood *et al.* 2013). As a result, there is considerably more knowledge available in unpublished data and angler knowledge than in the published literature.

Papua New Guinea is at a crossroads, with many direct and indirect threats to natural ecosystems. Consequently, there is a need to ensure that the drive to extract natural resources and the rapid growth of industry does not lead to irreversible changes to the environment, changes likely to affect species and habitat conservation, as well as the long-term food security for local people. The primary impacts on aquatic ecosystems in developing countries often come from urbanisation, but these manifest themselves in different ways depending on location and context. For example, besides a few coastal cities, such as Port Moresby, Lae and Madang, most of PNG's population is village-based (Rogers *et al.* 2011). However, PNG's rapid population growth (World Health Organisation, 2014) leads to increasing village urbanisation that tends to cluster around rivers and estuaries because of the many resources available from aquatic systems.

Papua New Guinea's aquatic ecosystems are also threatened by the expansion of large-scale plantation agriculture, mining and logging. For example, plantations encroach on riverbanks and wetlands, and high rainfall and soils with high hydraulic conductivity coupled with elevated nutrient levels within plantations (Nelson 2003) mean plantation agriculture can export substantial amounts of extraneous nutrients (Brodie *et al.* 2003) and sediment (Brodie & Turak 2012) into aquatic ecosystems.

Increasing population is the primary driver of community concerns among local populations in countries such as PNG (Butler *et al.* 2014), leading to a primary focus among local people and regional government on strategies to improve garden and agricultural productivity. Consequently, protection of the environment is a subsidiary concern, even though environmental degradation is a looming problem in the medium term (Butler *et al.* 2014), and despite well-managed ecosystems being key to livelihood resilience (Bell *et al.* 2009) and to the development of sustainable alternative livelihood solutions such as ecotourism (Wood *et al.* 2013).

The PNG government recently initiated a multidisciplinary research programme to sustainably develop, grow and manage the expanding sport fishing industry for the benefit of local communities in PNG. The long-term goals of this project are for a sustainable sport fishing industry to foster environmental stewardship and to provide alternative livelihoods and economic growth for local communities. The project will examine all aspects of the sport fishery, including the biology and ecology of the target species, impacts of the fishery on the species and economic and social issues relevant to the realisation of genuine conservation and sustainable livelihood outcomes for local people and the broader economy of PNG.

The first step in this process is to assess what is currently known about the biology and ecology of *L. goldiei*, the focal species of the sport fishing industry. The aims of this study were to bring together the published literature, analyses of unpublished data and interviews with anglers and local fisheries officers active in PNG to assess the current conservation status of *L. goldiei,* make a preliminary evaluation of threats to its key habitat and biological resources and identify critical knowledge gaps confronting the effective management of this species into the future.

Methods

Baseline knowledge

An exhaustive search was made for published (Table 1) and unpublished data about *L. goldiei*. Unpublished data were sourced through contacts in scientific, consultancy and conservation organisations active in PNG. Preliminary investigations indicated that much of the biological information in the published literature was based on references to previous work. As a result, each reference to *L. goldiei* was traced back to determine its original source and the extent to which it was based on data versus anecdotal evidence (Table 2). Existing data were supplemented with semi-structured interviews with Australian anglers who pioneered *L. goldiei* sport fishing in PNG and hold multiple IGFA world records, PNG sport fishing guides from long-running businesses, and PNG fisheries officers. The aim of these interviews was to obtain more detailed information on the distribution of *L. goldiei*, that is in which river systems and regions the interviewees could confirm *L. goldiei* occur, and the within-system distributions and habitats occupied by *L. goldiei*.

Distribution

The geographic extent of the range of *L. goldiei* was determined from the published and unpublished literature (Table 1), interviews and anecdotal reports from other sources (e.g. fishing magazines). Reported occurrences were considered reliable if based on scientific surveys, observations of fisheries officers or captures by experienced anglers and guides. Occurrences were considered likely but unconfirmed when reported from new locations within the confirmed range and derived from other sources such as unsupported statements in published articles or from magazine articles.

Table 1. Summary of a literature search of five on-line data sources using the term '*Lutjanus goldiei*' and its misspelling '*Lutjanus goldei*' (accessed 26/03/2014)

Source	Result	Peer reviewed articles	Reports/ databases/species lists
Web of Science	0 records	–	–
Aquatic Sciences & Fisheries Abstracts	0 records	–	–
Scopus	0 records	–	–
Google Scholar	11 records	7	4

At a finer scale, two data sets collected during previous studies of the condition of PNG's coastal waterways were analysed to assess within-system and habitat-specific distribution of *L. goldiei*; one from a study conducted in Mullins Harbour at the easternmost end of the PNG mainland (Fig. 1) (M. Sheaves, unpublished data) and a second conducted in the Kimbe Bay area of West New Britain (Fig. 1) (Nelson *et al.* 2014).

Mullins Harbour study background and methods

Mullins Harbour is a large mangrove-lined estuary system that opens onto the Coral Sea (Fig. 1). Annual average rainfall is approximately 3 m with heavy rainfall throughout the year (minimum monthly average 140 mm in December; maximum monthly average 310 mm in May)(www.weather-and-climate.com) (Weather and climate, 2014) meaning there is usually a strong salinity gradient from fresh water at the head of the estuary where the Sagarai River enters, to near sea water at the mouth of the Harbour. This salinity gradient was confirmed by extensive salinity sampling across Mullins Harbour at low tide on 23 March 2004 that provided a detailed snapshot of the spatial salinity profile.

The Mullins Harbour fish survey comprised data collected by line fishing over four trips between May 2001 and January 2004 (Fig. 2). Fish were collected by casting artificial lures close to fallen trees and roots along mangrove banks. Artificial lures are the main method used to capture *L. goldiei* by sport fishers and are one of the few reliable ways to capture this structure-associated

Table 2. Summary of published information on *Lutjanus goldiei*. Literature used only to delineate global distribution (Fig. 1) are not included. 'Source' is the publication making the statement cited, while 'Ultimate source' indicates the original data, observation or anecdotal report on which the statement is based.

Topic	Information	Source	Ultimate source	Details	Comment
Global Distribution	Globally restricted to New Guinea (inc. PNG to West Papua)	Allen (2004)	Various	Data from fish collections	Reliable identification from fish collections
	Occurs in Ryuku Islands, Japan	Senou and Suzuki (1992)		Diver observation	Likely mis-identification: 3000 km beyond confirmed range
Within-system distribution	Live entirely in freshwater	Gehrke *et al.* (2011)	Allen (2004)	Allen (2004) noted adults appear restricted to freshwater	Anecdotal - no confirmed observations in marine waters
	Occurs 1000 km up Fly River	Swales *et al.* (2000)		Data from fish collections	Reliable identification from fish collections
	Occupies oxbow lagoons	Swales *et al.* (2000)		Data from fish collections	Reliable identification from fish collections
Ecology	Does not enter marine waters to spawn	Allen (2004)	R. Moore pers. comm.	Suggested spawns in upper tidal reaches	Anecdotal
	Spawns in marine waters	McDowall (1988)	A.D. Lewis pers. comm.	Spawning grounds not confirmed	Anecdotal
	Presumably lays pelagic eggs	Coates (1993)	Breder and Rosen (1966)	General summary for Lutjanidae	No data for *L. goidiei*
	Feeds on fish, macroinvertebrates, terrestrial vertebrates (frogs, lizards)	Storey & Yarrao (2009)	Maunsell & Partners (1982)	General diets of group of predatory fish including bass	No specific data for *L. goidiei*
Fisheries	Worlds toughest sport fish	Kreh (2012)		Authors personal experience	Opinion
	High economic value	Gehrke *et al.* (2011)		Deduction based on recreational sport fishery operations	No specific economic data
	Stock in decline in Fly River	Gehrke *et al.* (2011)	Storey *et al.* (2009)	Declined at 2 of 12 sites in Fly River	Data from fish sampling surveys
	Important food fish for villagers along Fly River	Hortle (1986)		Observations	Observation
	Catfish prefered food fish over black bass	Swales (2001)		Observations	Observation

species (Kreh 2012). A similar approach has previously been used to sample the congeneric mangrove jack, *L. argentimaculatus* (Forsskål), in northern Australia (Sheaves 1995; Sheaves & Molony 2000). Sampling was conducted in nine sites comprising individual tributaries or the banks of deltaic islands around Mullins Harbour, with each site visited on at least two occasions.

Because sampling effort could not be standardised, analysis was restricted to presence/absence, except for the overall summary of total catch. The capture data set was interrogated to determine the distribution of *L. goldiei* compared to other sport fish across the Mullins Harbour sites, and assemblage patterns in the multivariate presence–absence data modelled using non-metric multidimensional scaling (nMDS) based on Sorensen similarity index. Gut content analysis was conducted to provide information on the diet of *L. goldiei* compared to the other sport fish captured. Prey were identified as far as possible, and diet composition was quantified by recording the presence of each prey type in each gut examined (Baker *et al.* 2014). Gillnet, seine net and cast net sampling was also conducted in the Mullins Harbour sites but produced no *L. goldiei* or other lutjanids. Although the collection of these fish provided the opportunity to collect additional biological samples (e.g. otoliths), *L. goldiei* were not the focus of this study, and such samples are not available.

Kimbe Bay Study Fish sampling in Kimbe Bay occurred in June and September 2011 and involved a combination of underwater video and collections with

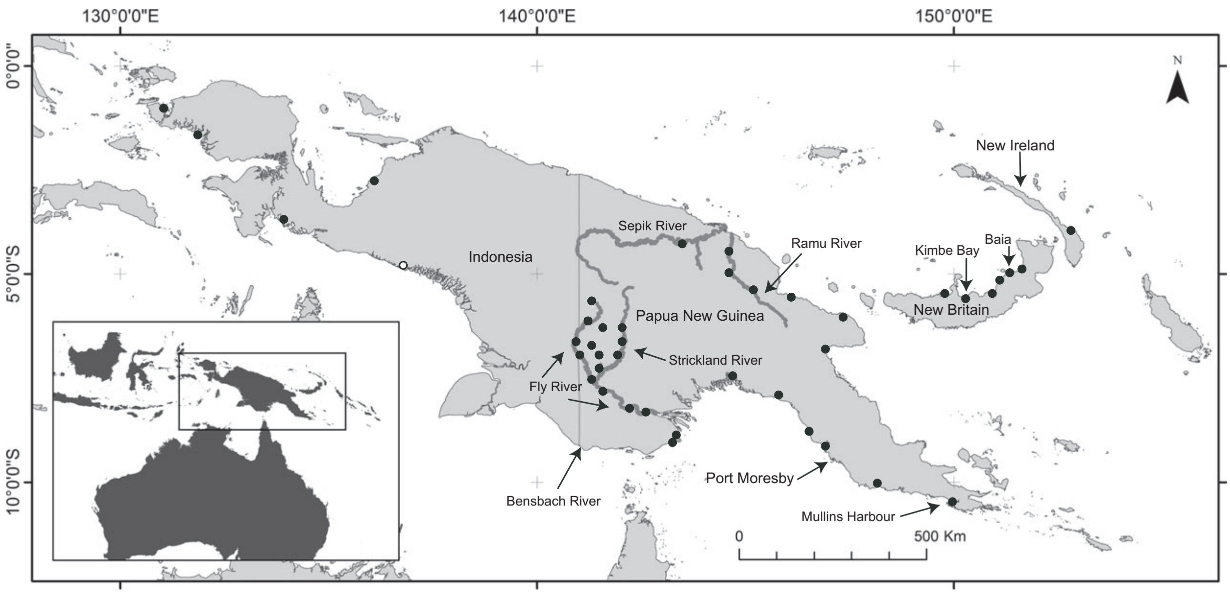

Figure 1. Geographic distribution of *Lutjanus goldiei*. Filled circles indicate reliable records of *L. goldiei* presence; the open circle is an unconfirmed report. The Kimbe, Baia and Mullins Harbour study sites are indicated, as well as the PNG capital Port Moresby.

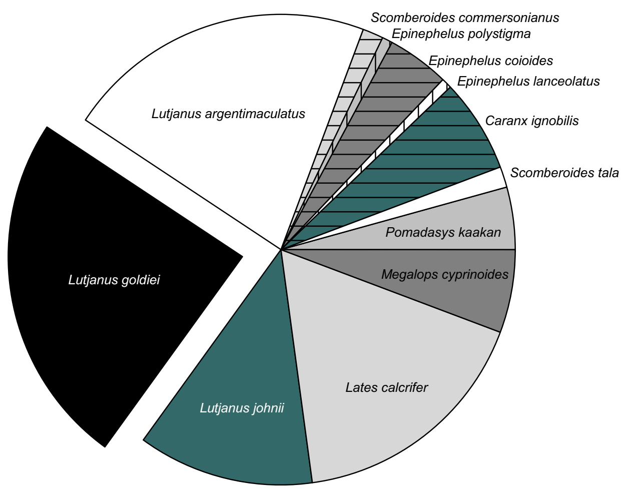

Figure 2. Species composition of fish collected by line fishing over four trips in Mullins Harbour between 2001 and 2004.

cast nets, dip nets and fyke nets (Nelson *et al.* 2014). As in Mullins Harbour, no *L. goldiei* were collected by netting. A total of 132 video replicates were collected across seven river systems. Each replicate involved a 15-min deployment, and samples were spread along each river from the estuary to upper freshwater reaches. The cameras were deployed to represent the range of habitats available in each reach of each river, including open unstructured habitats, fallen trees, mangrove roots, aquatic vegetation, steep banks and rock/cobble habitats.

Results

Geographic distribution

Based on the available reports and data, *L. goldiei* appears to be restricted to the coastal rivers around the islands of New Guinea, New Britain and New Ireland (Fig. 1). The distribution of confirmed and unconfirmed occurrences suggests that it occupies most coastal rivers on the New Guinea mainland with the apparent exception of those along the southern coast, south-west of the mouth of the Fly River (Fig. 1). There was an isolated report of *L. goldiei* from Iriomote Island, in southern Japan (Table 2; Senou and Suzuki 1992). This is about 3000 km north of any other reports and therefore appears likely to be a misidentification, so was not included as part of the geographic distribution. There are also reports of black bass from Borneo (on fishing websites), but whether these are *L. goldiei* remains to be confirmed, and these were also left out of the geographic distribution.

Within-system distribution

The occurrence data used to delineate the known range of *L. goldiei* (Fig. 1) also provide within-system distribution information that suggests they are distributed throughout coastal rivers, from saline river mouths to the upper reaches of the coastal floodplain freshwater, with records from about 1000 km upstream in the Fly River near the base of the central ranges (Fig. 1, Table 2). *Lutjanus* *goldiei* have been collected from off-channel oxbow lagoons along the Fly River (Storey *et al.* 2008), and expert guides report capturing them from the lower estuary through to upstream freshwater areas, and in both riverine and connected off-channel lagoons elsewhere in their range.

The distribution of species within the sport fish assemblage in Mullins Harbour correlated with an upstream–downstream salinity gradient, with catches at the low salinity sites characterised by high occurrences of barramundi, *Lates calcarifer* (Bloch), and higher salinity sites around the Harbour characterised by a range of species including the congeners of *L. goldiei*, *Lutjanus johnii* (Bloch) and *L. argentimaculatus* (Fig. 3). By contrast, *L. goldiei* occurred throughout Mullins Harbour regardless of salinity so does not appear as an influential species in the ordination (Fig. 3).

The Kimbe fish survey recorded *L. goldiei* in 10 videos from two rivers, the Dagi and Papuni. The majority of individuals observed were small juveniles (<10 cm) based on the distinct colouration patterns common in small juvenile lutjanids. *Lutjanus goldiei* were observed from saline estuarine sites through to freshwater sites on the coastal plain of each river.

Habitat occurrences

All *L. goldiei* captured in Mullins Harbour or recorded on video in Kimbe were in close association with fallen

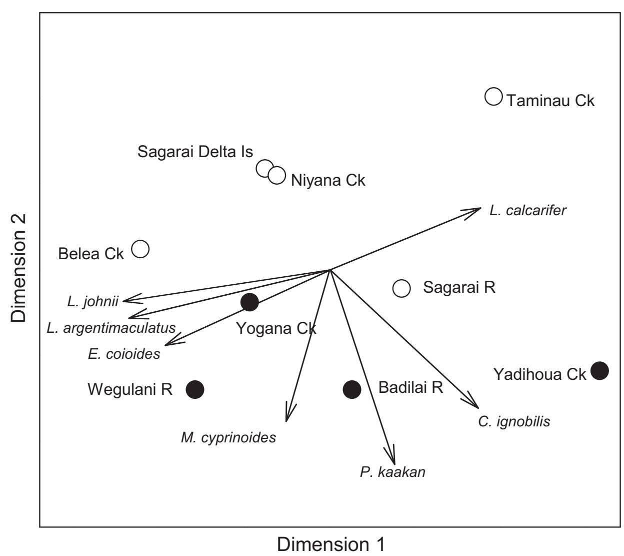

Figure 3. Multidimensional scaling of fish presence/absence data for fish collected from Mullins Harbour fish between 2001 and 2004. The ordination is based on Sorensen distance with stress = 0.04. ○ = low salinity sites, ● = higher salinity sites. Vectors indicate the direction of increase in occurrence across the ordination space for species highly correlated with the space ($r > 0.65$). Note: there is no vector for *Lutjanus goldiei* because it occurred across all sites so is not influential in the ordination.

trees, mangrove roots or aquatic vegetation. This close association with woody structure accords with consensus among the experts interviewed that the larger individuals targeted by the sport fishery are strongly associated with snags formed by fallen trees and tree roots. *Lutjanus goldiei* is also captured by anglers along the edges of grass beds, and may be captured some distance from visible snags where water bodies mix, such as inflows from oxbow lagoons and swamps to the main river channel.

Diet

The 34 *L. goldiei* from Mullins Harbour were collected across all four trips, with at least eight fish from any one trip. All individuals would be considered small-medium fish by the sport fishery (38–57 cm). Their diets were dominated by crabs (present in all 31 individuals with non-empty guts), with minor contributions from penaeids (six individuals) and fish (five individuals) (Table 3). This diet was indistinguishable from the closely related *L. argentimaculatus*, which also fed predominantly on crabs. This differed from the diets of non-lutjanids collected at Mullins Harbour. For instance, the haemulid, *Pomadasys kaakan* (Cuvier), had only consumed bivalves, while the diets of other species primarily comprised fish and penaeids (Table 3). Storey & Yarrao (2009) reported that, together with other large predatory species, *L. goldiei* feed on fish, crabs and other macroinvertebrates, and terrestrial vertebrates such as frogs and lizards (Table 2). Although no specific dietary data for *L. goldiei* were presented by Storey & Yarrao (2009), their reports are consistent with the observations of the fisheries officers, anglers and guides interviewed. For example, 17 *L. goldiei* captured by anglers at Baia in West New Britain (Fig. 1) in May 2013 were examined for gut contents, and the six individuals containing prey all consumed crabs.

Spawning locations

While anglers report capturing *L. goldiei* in the mouths of estuaries, there are no confirmed reports from coastal marine waters outside estuaries. Spawning locations remain unknown, with conflicting anecdotal reports (Table 2) that they do not enter marine waters for spawning, but spawn in the upper tidal reaches of estuaries (Allen 2004), or that they spawn in marine waters (McDowall 1988). One of the largest individuals (770 mm) caught in a freshwater section of a river during the fishing surveys at Baia had large ovaries with well-developed eggs.

Table 3. Prey in the stomachs of fish caught during fishing surveys in Mullins Harbour.

		Prey category						
Species	Common name	Sesarmind (mangrove) crabs	Penaeid prawns	*Macrobrachium* shrimps	Polychaetes	Fish	Bivalves	Insects
Acanthopagrus berda	Pikey bream	✓	✓	✓	✓		✓	
Caranx ignobilis	Giant trevally		✓			✓		
Caranx papuensis	Papuan trevally		✓			✓		
Caranx sexfasciatus	Big-eye trevally		✓			✓		
Epinephelus malabaricus	Malabar grouper	✓		✓				
Lutjanus johnii	John’s snapper		✓			✓		
Lutjanus russellii	Russell’s snapper		✓	✓				
Pomadasys kaakan	Spotted javelinfish		✓				✓	
Scomberoides commersonianus	Common queenfish		✓			✓		
Scomberoides tala	Barred queenfish					✓		
Sphyraena barracuda	Giant barracuda					✓		
Toxotes chatareus	Largescale archerfish	✓						✓
Tylosurus crocodilis	Hound needlefish					✓		
Tylosurus gavialoides	Stout longtom					✓		
Epinephelus polystigma	White-dotted grouper	✓						
Lates calcarifer	Barramundi		✓	✓		✓		
Lutjanus argentimaculatus	Mangrove jack	✓	✓			✓		
Lutjanus goldiei	Papuan black Niugini black bass	✓	✓			✓		

Discussion

Although first described in 1882 by Macleay, Allen (2004) reported that almost nothing was known about the life history of *L. goldiei*, and not much has changed in the subsequent 10 years. Despite the limited data, the available information provides some important insights into the ecology of the species, which provide for a preliminary evaluation of the key threats, and highlight critical areas for future research to ensure the sustainable development of *L. goldiei* sport fishing during a time of rapid change.

Distribution and ecology

Lutjanus goldiei has long been considered as restricted to the coastal rivers between Port Moresby and the Fly River (e.g. current distribution listed on www.Fishbase.org). However, as far back as 2004, Allen (2004) noted the distribution extended around most of mainland New Guinea. The additional data reported in the present study extend this to include the adjacent islands of New Britain and New Ireland (Fig. 1). Despite this extension to the known range, *L. goldiei* still appears to have a limited distribution on a global scale. The single report of *L. goldiei* from Iriomote Island, Japan (Senou & Suzuki 1992), 3000 km to the north of New Guinea is likely a misidentification of a closely related species, because there have been no confirmed reports from anywhere beyond New Guinea and nearby islands. Indeed, until the reviews of the genus *Lutjanus* by Allen and Talbot (1985) and Allen (1985), there was uncertainty of the validity of *L. goldiei* as a separate species, with frequent misidentification as the mangrove jack *L. argentimaculatus* (Allen 2004). From a sport fishing perspective, the limited distribution means that it is a unique product to market and makes it more attractive as a flagship species to attract visitors to PNG. There are also reports of black bass from Borneo (on fishing websites), but if these are *L. goldiei* is yet to be confirmed, and this remains an intriguing area for future research.

Lutjanus goldiei appears to be present in most, but not all coastal rivers and streams around New Guinea and the adjacent islands (Fig. 1). Experienced *L. goldiei* anglers have been fishing the area around the Bensbach River near the southern border between PNG and Indonesian West Papua (Fig 1.) for over 30 years and report that *L. goldiei* are not captured there.

Lutjanus goldiei was previously considered to be primarily or exclusively restricted to fresh waters (Allen 2004). However, data from the current study and reports from expert anglers and guides indicate that *L. goldiei* is also common in the saline reaches of estuaries, including individuals from small juveniles to large adults.

The location of spawning remains unknown (Table 2). Most *Lutjanus* species are marine spawners (Breder &

Rosen 1966), and it therefore seems likely that *L. goldiei* would spawn in the saline portions of estuaries or in marine waters. However, *L. goldiei* has never been identified during extensive fish surveys on coastal reefs in Kimbe Bay, West New Britain (G. Jones pers. comm.) or West Papua (Allen & Erdmann 2009), despite these reefs being adjacent to rivers in which *L. goldiei* is abundant. Together with the observation of a single egg-bearing female from within a river near Baia, and the likelihood of a protracted spawning season rather than a pronounced spawning event (Russell & McDougall 2008), this evidence suggests that *L. goldiei* may well spawn within estuaries (Allen 2004), or that if they do migrate to marine waters to spawn (McDowall 1988), they probably do not move far or stay long outside the estuary.

Although based on limited data, the diet of *L. goldiei* was consistent among locations, and very similar to the better known diet of the closely related *L. argentimaculatus*, which feeds mainly on mangrove crabs in estuarine waters (Sheaves & Molony 2000). Further work is needed to understand the full range of food resources used by *L. goldiei* throughout its life and throughout the range of habitats occupied.

Threats and opportunities

Perhaps the most immediate threat to the conservation and sustainability of *L. goldiei* is a lack of knowledge of its life history. There are few data on its ecology beyond its general distribution (Table 2). Basic but critical biological information including population size, mortality rates, age, growth, timing and location of spawning, movement patterns, and the range of habitats and food resources used throughout its life are priorities for research to underpin the effective management of the species.

Papua New Guinea and the surrounding region are undergoing rapid population and industrial growth. Consequently, defining *L. goldiei* stock structure and the distribution of each stock is essential for assessing their vulnerability to impacts such as increased fishing and habitat degradation.

Detailed knowledge of the movement patterns and critical habitats for all phases of the life cycle of *L. goldiei* is necessary to determine the resources required by the different life-history stages and to define the timing of important movements such as spawning migrations and/or aggregations. However, nothing is known about the timing of *L. goldiei* movements, the purpose of such movements and how this may vary with ontogeny. In particular, there is no information on the movement of adults in relation to their reproductive cycle, and little data on the range of habitats used by the different stages of the life cycle.

Movement studies (acoustic and conventional tagging, and natural marker techniques) in conjunction with genetic analysis will also help identify any possible connectivity between *L. goldiei* populations in different systems. If adults move offshore to spawn and/or larvae are dispersed through coastal or marine waters, this would facilitate genetic mixing between stocks. This is the case for its close relative *L. argentimaculatus*, where offshore spawning facilitates considerable genetic mixing in eastern Australia (Ovenden & Street 2003). Alternatively, fish migrating between rivers may connect populations. Resolving the extent and pattern of connectivity among rivers is crucial because the extent of connectivity determines whether an overfished system could be naturally replenished by the influx of larvae, juveniles or adults from other areas. If adult or larval dispersal among river systems is limited, it may be important to manage the fishery at the scale of individual rivers. This is a critical issue in a developing country where local livelihoods and food security are tied to events and outcomes in the area controlled by a community; while a tourism operator can simply move to new waters to ensure acceptable catch rates for clients, local villagers will lose out if their stocks of the larger fish prized by the sport fishery are depleted.

At a more local scale, maintaining within-system connectivity and the protection of key habitats are crucial to maintaining healthy *L. goldiei* populations. *Lutjanus goldiei* is found from the mouths of estuaries through to upstream freshwater reaches. This suggests that individuals may move along the length of rivers during their lives. Therefore, maintaining connectivity between the freshwater and estuarine reaches of river systems is likely to be important for *L. goldiei* conservation. Physical (e.g. dams) and pollution barriers (e.g. water quality) are two of the main impacts that could disrupt this connectivity in PNG (Storey *et al.* 2009, Arthington *et al.* 2010) and have already led to substantial degradation of estuarine and riverine habitat values in nearby northern Australia (Sheaves *et al.* 2014). A healthy river with an intact riparian zone continually provides critical snag habitats (Boyer *et al.* 2003; Caddy 2008), habitats that seem particularly important for *L. goldiei*. However, the widespread loss of riparian zones through industry (logging, agriculture, mining) and urbanisation (e.g. home garden patches along river banks) in many PNG rivers will reduce the amount of new snag habitat generated with the potential for significant negative impacts on *L. goldiei* populations.

There is some indication that *L. goldiei* populations or catches could be negatively affected by sport fishing activities. The sport fishery appears to be largely catch and release, but there are no formal regulations relating to sport, subsistence or artisanal fisheries for the species, and no information about post-release survival of fish captured in the sport fishery. In Baia, a near-pristine region in the north coast of West New Britain, a sport fishing operator who fishes in several rivers in the area reported decreasing catches since 2008 (Reimann, pers. comm). There is a perception among locals that the lack of recaptures results from fish learning to not take lures. The higher turbidity due to increased logging in some of the rivers' catchments in recent years is also thought to be a contributing factor to reduced catches of these visual predators. However, even when waters are clear, catches around Baia are still reported as low in comparison with previous years. Research to determine the extent to which declining catches are due to reductions in *L. goldiei* populations from high post-release mortality, fishing pressure from local people or sublethal impacts from catch and release will be important to help define the pattern of management of *L. goldiei* and their fishery.

Conclusions

Lutjanus goldiei is a large, highly prized sport fish species with a limited geographic range. Implementing realistic management strategies will be challenging because little of the necessary knowledge about the ecology of this species exists. Key knowledge gaps include stock size and structure, mortality rates, size at maturity and reproductive cycle, habitat use, movement patterns, spawning patterns and sites, and foraging behaviour; all essential to underpin management strategies and policy decisions.

However, a well-planned fishery requires more than just ecological information (Wood *et al.* 2013), particularly in the context of a developing country where sustainable industries are needed to support livelihoods and provide basic income streams (Butler *et al.* 2014). This requires a multidisciplinary approach that brings together biological, ecological, environmental, social and economic research, to support the development of a sustainable and resilient locally based sport fishing industry. Such integrated research can provide the background knowledge needed to support the development of stable alternative livelihood opportunities for coastal villages. At the same time, the awareness of the need to protect the habitats of species such as *L. goldiei* can promote a new level of environmental awareness among local people and central governments alike, leading to the likelihood of substantial environmental benefits (Carana Corp 2012). These benefits would be both direct, by generating the knowledge needed to manage these poorly understood resources and, indirectly, by increasing awareness of the value of local ecological and environmental resources, creating incentives to conserve the target species' key habitats, by helping develop the capacity to implement local-level management and providing the knowledge on which to base sound conservation and management plans.

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