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Assessing Impacts and Local Perceptions Following the Incidental Introduction of tilapia (Cichlidae: Cichliformes) in a Remote Inland Fishery in Papua New Guinea

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Abstract

Introductions of non-native fish are intended to have positive social outcomes, although they can also result in negative environmental consequences. Recently, incidental introduction of tilapia (*Oreochromis* cf. *niloticus*) was recorded in the Kikori River, Papua New Guinea. This study investigated the abundance of *Oreochromis* cf. *niloticus* relative to native fish species in the Kikori Town market, and interviewed market vendors to gauge the local perception of *Oreochromis* cf. *niloticus*. Market data were collected over eight days with 1474 individual fish observed. *Oreochromis* cf. *niloticus* comprised 11.4% (n = 168) of fish and was the largest contributor of biomass (40.2%). Market vendors reported that *Oreochromis* cf. *niloticus* was easy to catch and sell, and ranked it highly in sale preference compared to native species. There is potential to explore export markets for Kikori River *Oreochromis cf. niloticus* in PNG's highland provinces to expand economic opportunities for local communities.

Keywords Ecosystem Services · Introduced Species · Livelihoods · Inland Fisheries · Subsistence · Tilapia · Kikori River · Papua New Guinea

Introduction

Inland fisheries play an important role in social and economic livelihood aspects of many developing nations across the globe (Funge-Smith, 2018; Ainsworth et al., 2021). Typically, inland fisheries are small-scale or subsistence in nature, mainly contributing directly to consumption or sale at local markets (Fluet-Chouinard et al., 2018). In low-income nations with dense human populations or nutrition deficit problems, non-native fish introductions have been a common approach to improve food and economic security of local resource users (Deines et al., 2016). For example, several lakes and rivers of Africa have been stocked with species such Nile tilapia *Oreochromis niloticus* and kapenta *Limnothrissa miodon* with the intent of alleviating food security concerns and providing a source of income (Ellender et al., 2014). However, non-native fish introductions can lack consideration for the negative effects that may subsequently arise for native species, or the broader ecosystem services (goods and other resources that contribute to social, economic, and cultural wellbeing, Reid et al., 2005) (Deines

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et al., 2016). The introduction of Nile perch *Lates niloticus* in Lake Victoria resulted in severe native species declines or extinctions, leading to degraded habitat quality, and collapse of cultural fisheries (Aloo et al., 2017). Ultimately, the perceived effects (positive or negative) of non-native fish introductions on ecosystem services will be dependent on many factors, such as the time since the introduction, the pre-existing state of the ecosystem (e.g., presence of other non-natives or other environmental degradation factors), and the socioeconomic and cultural setting prior to introduction (Deines et al., 2016).

Over the past century many national governments and international agencies, e.g., World Health Organisation and the Food and Agriculture Organization of the United Nations, have actively facilitated the introduction of tilapia (Cichlidae) into impoverished areas for the purpose of increasing fisheries productivity and addressing nutritional problems (Dudgeon & Smith, 2006; Deines et al., 2016). For such purposes, tilapia are an ideal candidate as they have a wide range of environmental tolerances, broad diet, and highly productive reproductive characteristics that allow them to quickly adapt and proliferate in tropical inland aquatic environments (Canonico et al., 2005). Generally, the perceived effects of tilapia introductions on ecosystem services varies globally and is context specific (Deines et al., 2016). Tilapia introductions have successfully provided additional food security and socioeconomic opportunities, and boosted fisheries GDP in some nations, e.g., Sri Lanka (Deines et al., 2016), although in other areas they have simultaneously had a negative impact on native species (Canonico et al., 2005). Furthermore, tilapia are rarely contained to their intended introduction site, and are considered to be highly problematic invasive species (Canonico et al., 2005; Arthur et al., 2010).

Papua New Guinea (PNG) is located east of Indonesia and within the megadiverse Coral Triangle. Compared to the broader Indo–West Pacific, PNG is characterised by low human population density, with much of the population living at least in-part by traditional subsistence means. Among various health and livelihood challenges across the nation, access to protein and income opportunities have been two problems that authorities have sought to address through non-native fish introductions and small-scale aquaculture (Coates, 1987; Dudgeon & Smith, 2006; Pickering, 2009). Across regional PNG, between 10,000 and 20,000 'household scale tilapia farms' are thought to exist, making PNG a leader among Pacific Island nations in the adoption of tilapia for improved social and economic purposes (Pickering, 2009). There is a lack of information however about the impact of tilapia on native species and fisher livelihoods in PNG. For example, Mozambique tilapia *Oreochromis mossambicus* were introduced to the Sepik River in the 1950s along with several other species (Dudgeon & Smith, 2006) and by the 1980s they constituted about half of inland fishery landings (Coates, 1985). However, subsequent declines in native fish species (Sari et al., 2005) has led to a negative perception of the role non-native fish have had on the Sepik River's biodiversity, despite the intended benefits (food and economic security) provided for inland fisher livelihoods (Dudgeon & Smith, 2006).

One region of PNG where tilapia has been late to arrive is the Gulf Province, in the country's south. This region has a low human population density and has not been subject to intensive fishing practices historically. In the 1990's, the common carp *Cyprinus carpio* and two species of tilapia *O. mossambicus* and redbreast tilapia *Coptodon rendalli* were introduced into small-scale aquaculture ponds the Lake Kutubu region within the Kikori River catchment, with the aim of increasing local food security (Imbun & Mondu, 2011). In 2009, small-scale aquaculture was revisited at Lake Kutubu and genetically improved farmed tilapia (GIFT) *Oreochromis niloticus* were stocked along with water hyacinth *Eichhornia crassipes* (as food for *O. niloticus*), following success in other highland regions of PNG (Smith, 2007). However, during large wet season rains in 2010–2012, *O. niloticus* were washed into Lake Kutubu. In 2015, locals reported that catch in Lake Kutubu was dominated by 'tilapia', and that catch of native species had decreased markedly (Smith et al., 2016).

Downstream of Lake Kutubu in the broader Kikori River catchment, the presence and effects of non-native fish on the Kikori River inland small-scale fishery is unclear. Eisemberg and Berra (2016) provided the only available preliminary observations of species sold at Kikori Town Market (situated in the lower freshwater reaches of the Kikori River) in January 2012. A total of 16 native species (encompassing 10 families) were observed in these surveys. Shortly after, the arrival of tilapia (identified as *Oreochromis* sp.) was reported by Georges (2013) from Wau Creek in the Kikori River's lowland headwaters down to the estuarine environments of the upper Kikori River Delta. Considering the absence of tilapia in observations by Eisemberg and Berra (2016), it is likely that tilapia arrived in the low land reaches of the Kikori River after January 2012, or they were only present in low numbers at the time (Georges, 2013). The origins of tilapia in the lower Kikori River is likely the result of escapees from aquaculture practices around Lake Kutubu (Georges, 2013), and their presence in the Kikori River represents an unintended introduction. Anecdotal observations by the Piku Biodiverty Network (a local non-government organisation) indicate that tilapia are now abundant throughout the Kikori River. Owing to the recent arrival of tilapia and the availability of fisheries data prior to their arrival (Eisemberg & Berra, 2016), there is presently an opportunity to investigate the effects of tilapia on small-scale fisheries landings and to gauge the perceptions of local fishers around their arrival.

The present study aimed to: (1) determine the abundance of tilapia in the Kikori local market relative to native fish species and compare species composition to Eisemberg and Berra (2016); (2) determine body condition (as a measure of body mass from length-weight relationships) of tilapia relative to native fish species; and, (3) provide preliminary insight into the use and value of tilapia to local fishing communities, and gauge any concerns about its presence. This study will help to inform local fisheries management on the status of tilapia populations in the Kikori River and provide a baseline to measure changes to native fish diversity and the effects on livelihoods of local fishers in the future.

Methods

The two primary approaches for data collection in this study were to: (1) record fish species at the Kikori Town market; and (2) conduct a semi structured interview questionnaire with market vendors.

Market Observations

Market observations were conducted at Kikori Town Market over eight days between October 13th and November 2nd. Cultural advice and translations were provided by one of us (YA) who facilitated interactions with local vendors selling fish at the time of visit. Each vendor was asked for the location where they had captured any fish they were selling, what fishing equipment was used (e.g. gillnet, bow and arrow), their tribal identity, and their traditional language name for each type of fish they were selling. Condition of fish (fresh or preserved; preserved encompassed any preparation methods such as drying, smoking, or frying) were recorded, and taxonomic identifications were made to the highest resolution possible using various taxonomic databases (e.g., https://fishesofaustralia.net.au*)* and local fish fauna guides (e.g., Allen, 1991). Most specimens were identifiable to species level, although due to preparation (e.g., smoking for preservation), time constraints, and cryptic diversity within the various catfish families and mullet family, all catfishes were recorded at order level, i.e. Siluriformes, and all mullet were recorded at family level, i.e. Mugilidae. For catfishes and mullet, these broad identifications also ensured specimens were documented before sale, and minimised the disruption to local vendors. For all specimens observed at the market, total length (TL) was measured to the nearest millimetre (mm), from the snout to the termination of the tail using a measuring board. Weight was measured in kilograms (kg) to two decimal places, using a handheld digital scale. The advertised price of each individual fish was also recorded in local currency (Papua New Guinean Kina, PGK).

Market Observation Data Analysis

The total number of observations and weight of each taxonomic grouping and fish condition (i.e. fresh or preserved) was calculated in Microsoft Excel. The range and mean for size, weight, and price was also calculated for each taxonomic grouping.

Length-Weight Relationships

To assess length-weight relationships (LWR), linear regression models were fitted following Ogle (2016) whereby, raw length (cm) and weight (kg) are linearized by log-transforming both variables. Only species with >30 fresh specimens were considered for this analysis. The relationship between the log-transformed measurements of length (L) and weight (W) was expressed as:

$$\log_{10}W = \log_{10}a + b\log_{10}L.$$

where $\log_{10}W$ is a linear regression line with slope b and y-intercept $\log_{10}a$. In this equation, b can be used as a measure of body condition whereby, when $b=3$ there is no change in body mass relative to length, when $b<3$, body mass reduces relative to length, and when $b>3$ body mass increases relative to length (Froese, 2006). In interpretating b, it is important to consider ontogenetic changes in body form and shape, and that factors such as reproductive stage and stomach contents of the sample size can influence the value of b (Froese, 2006). Back-transformed estimates of a and the standard error of b were obtained by using the model output values as the exponent to the base of the logarithm (Ogle, 2016). To minimise bias, back-transformed estimates were then multiplied by a correction factor computed using the Fisheries Stock Analysis package *FSA* v. 0.8.30 (Ogle et al., 2020). All data analysis was conducted in version 3.5.2 of the R statistical programming environment.

Market Vendor Interviews

Active market vendors were selected for interviews, based on availability during market visits (i.e. no *a priori* selection of particular community members who are known to sell fish was made). Where multiple market vendors were selling fish during a particular market visit, interviews were conducted sequentially along the 'line' of sellers in the 'wet' part of the market.

Participation for market vendors was voluntary. Prospective interviewees were firstly briefed on the context of the study, types of questions they would be asked, and that the study was being conducted through James Cook University in collaboration with the Piku Biodiversity Network. Prospective interviewees were made aware that the answers they provided would contribute to a study on Kikori Town market, which would be made available to local, provincial, and national management sectors. It was also made clear to all prospective interviewees that their answers would be audio recorded, and they would not be personally identifiable as a result of participating in the study. Following this, prospective interviewees were asked if they consented to participation.

The questionnaire used was structured into two sections with both open and closed questions (see Supplementary Information). The first section concerned selling, fishing, and location characteristics of the interviewee, followed by a set of questions about tilapia specifically. Interviewees were shown a picture of tilapia (*Oreochromis niloticus*) at question seven to ensure positive identification for subsequent tilapia specific questions.

The second section of the questionnaire targeted the expected sale prices for the five most abundant large-bodied (> 20 cm) species identified by Eisemberg and Berra (2016) compared to tilapia, when being sold fresh and preserved. For each of these six species, interviewees were asked which condition they preferred (fresh or preserved) for sale. Finally, interviewees were asked to rank the marketability of each of these six species and provide a reason for why they chose their highest and lowest ranked species.

Data Analysis of Interviews

Microsoft Excel was used to produce descriptive statistics. Responses to open ended questions were coded into categorical responses. The small sample size of interviewees made statistical comparisons inappropriate and so percentages, means and ranges are presented when suitable.

Results

Market Observations

In total, 1,474 individual fish were recorded at Kikori Town Market, comprising 17 species from 13 families (Table 1). In addition, catfishes (Siluriformes) were only identified to order, mullet (Mugilidae) were only identified to family, one specimen of flathead (Platycephalidae) could not be identified beyond family level due to its distorted condition from smoking. The tilapia species present appears to be GIFT *O. niloticus*, however due to the morphological similarities with *O. mossambicus* which may also be present (Imbun & Mondu, 2011), and potential of hybridisation between these species, it is tentatively identified as *Oreochromis* cf. *niloticus*. The total weight of fish recorded was 364.8 kg, with a value of 2792.20 PGK ($781.82 USD, 29/01/2022). The mean value of all fish being sold per vendor was 47.30 PGK (range 3.00–224.50 PGK).

Almost all fish observed were caught downstream of Kikori Town Market (Fig. 1), with the exception of 16 specimens of *Oreochromis* cf. *niloticus* from upstream. Four fishing gear types were reportedly used to capture the observed fish; hook and line (seven, 0.4%), bow and arrow (10, 0.6%), spear (16, 1%), and gillnet (1441, 98%). *Oreochromis* cf. *niloticus* were caught by bow and arrow, and spear, while one Papuan black bass *Lutjanus goldiei*, five scaly jewfish (locally called 'stone fish') *Nibea squamosa*, and one Siluriformes sp. were caught by hook and line. All other fish observed were caught using gillnets. Gillnet mesh sizes ranged from 1.5 inches (″) – 6″, while overlaid meshes of 2″ & 3″, 2″ & 7″, 3″ & 5″, and 4″ & 5″ were also reported. Of the 1,441 fish caught by gillnets, 923 (64.1%) were caught in mesh sizes < 4″, 196 (13.6%) were caught in mesh sizes ≥ 4″, and 322 (22.3%) were caught in overlaid mesh sizes. *Oreochromis* cf. *niloticus* were caught in mesh sizes ranging from 2–4″, and overlaid meshes of 2″ & 3″, 3″ & 5″, and 4″ & 5″.

The nursery fish *Kurtus gulliveri* was the most abundant fish in the market, comprising almost a third of the total fish observed (*n* = 440; 29.9%), followed by blue salmon *Eleutheronema tetradactylum* (*n* = 267; 18.1%), Mugilidae spp. (*n* = 211; 14.3%), *Oreochromis* cf. *niloticus* (*n* = 168; 11.4%), Siluriformes spp. (*n* = 126; 8.6%), and *N. squamosa* (*n* = 119; 8.1%) (Table 1). Three or fewer individuals were recorded for New Guinea tiger perch *Datnioides campbelli*, Barramundi *Lates calcarifer*, *L. goldiei*, Golden snapper *Lutjanus johnii*, Platycephalidae sp., and *Acanthopagrus pacificus*.

Oreochromis cf. *niloticus* comprised over 40% of the total fish biomass (146.8 kg, 40.2%: Table 1). This was triple the biomass of *N. squamosa* (54.6 kg, 15.0%), the second highest contributor to biomass. From all fish observed, only 110 (7.5%) of individual fish weighed > 1.0 kg. Of fish species with more than 5 individuals being sold fresh, *Oreochromis* cf. *niloticus* had the highest mean weight (1.0 kg) with 62.2% (84/135) being > 35.0 cm (range: 20.3–45.0 cm; Table 2). *Kurtus gulliveri* made up only 9.3% (33.8 kg) of the biomass, despite being the most abundant species observed. Only six individual fish weighed over 3.0 kg, with four king threadfin salmon *Polydactus macrochir*, one *N. squamosa*, and one *L. goldiei*. Over half of individual fish observed

Table 1 Local name, total abundance (n), weight (kg; kilograms), and value (PGK; Papua New Guinea Kina), for each species recorded at Kikori Town Market

Family	Species	Common name	Local name (tribe)	n (%)		Weight kg (%)		Value (PGK)
Ambassidae	*Parambassis gulliveri*	Giant glassfish	Goa/Goe (Uruma)	17	(1.15)	1.72	(0.47)	14.20
			Kada (Kerewo, Kibiri)					
			Pipihari (Kibiri)					
			Wohe (Uruma)					
			Avo (Kgo)					
Cichlidae	*Oreochromis* cf. *niloticus*	GIFT tilapia	Tilapia (all tribes)	168	(11.40)	146.75	(40.23)	890.00
Datinoididae	*Datnioides campbelli*	New Guinea tiger perch	Ubei (Kibiri)	1	(0.07)	0.29	(0.08)	2.00
Eleotridae	*Oxyeleotris lineolata*	Sleepy cod	Upa (Kibiri)	10	(0.68)	5.45	(1.49)	38.50
			Uperi (Borome)					
			Ubu (Uruma)					
Engraulidae	*Thryssa scratchleyi*	Freshwater anchovy	*Kirai'ia* (Kerewo)	6	(0.41)	0.29	(0.08)	3.20
Kurtidae	*Kurtus gulliveri*	Nursery fish	Eba/Aba (Uruma)	440	(29.85)	33.75	(9.25)	510.50
			Hago (Kerewo					
			Ebei (Borome)					
Latidae	*Lates calcarifer*	Barramundi	Kirabu (Kibiri)	2	(0.14)	1.13	(0.31)	8.00
Lutjanidae	*Lutjanus goldiei*	Pupuan black bass	Mai (Kiribi)	1	(0.07)	3.49	(0.96)	50.00
	Lutjanus johnii	Golden snapper	Bara (Kerewo)	2	(0.14)	0.51	(0.14)	4.00
Mugilidae	Mugilidae sp.	mullet	Maia (Uruma)	211	(14.31)	16.89	(4.63)	104.80
			Ivori (Kerewo)					
			Mako (Kgo)					
			Avai'i (Kibiri)					
Platycephalidae	Platycephalid sp.	flathead	Aria (Uruma)	1	(0.07)	0.13	(0.04)	2.00
Polynemidae	*Eleutheronema tetradactylum*	Blue salmon	Ee're (Kerewo, Uruma)	267	(18.11)	21.16	(5.80)	374.90
			Gaiha (Uruma)					
	Polydactylus macrochir	Threadfin salmon	Ee're (Kerewo)	27	(1.83)	28.01	(7.68)	91.50
			Gaiha (Uruma)					
Scatophagidae	*Scatophagus argus*	Spotted butterfish	Tiari/Teri (Kibiri)	21	(1.42)	3.6	(0.99)	28.00
			Wiba (Kerewo)					
			Opiaha (Uruma)					
	Selenotoca multifasciata	Striped butterfish	Wiba (Kerewo)	12	(0.81)	1.87	(0.51)	17.00
Sciaenidae	*Nibea squamosa*	Scaly jewfish	Hutu (Kerewo)	119	(8.07)	54.59	(14.97)	345.20
			Bukumatu/Bukumabo/ Bukumapou (Kibiri)					
			Puduma (Uruma)					
	Protonibea diacanthus	Black jewfish	Puduma (Uruma)	5	(0.34)	1.42	(0.39)	13.00
			Hutu (Kerewo)					
Siluriformes	Siluriformes spp.	catfish	Atu (Uruma)	126	(8.55)	35.11	(9.62)	223.60
			Avimoni (Rumu)					
			Balus (Borome)					
			Boromo (Kerewo, Kibiri)					
			Butus (Uruma)					
			Kamuteri (Borome)					
			Pario (Uruma)					
Sparidae	*Acanthopagrus pacificus*	Pikey bream	Uwaru (Kibiri)	3	(0.20)	3.02	(0.83)	17.00
			Ovaru (Kerewo)					
Toxotidae	*Toxotes chatareus*	Sevenspot archerfish	Botowari/Borowari (Kibiri)	35	(2.37)	5.6	(1.54)	54.80
			Boma (Uruma)					
Totals				**1474**		**364.78**		**2792.20**

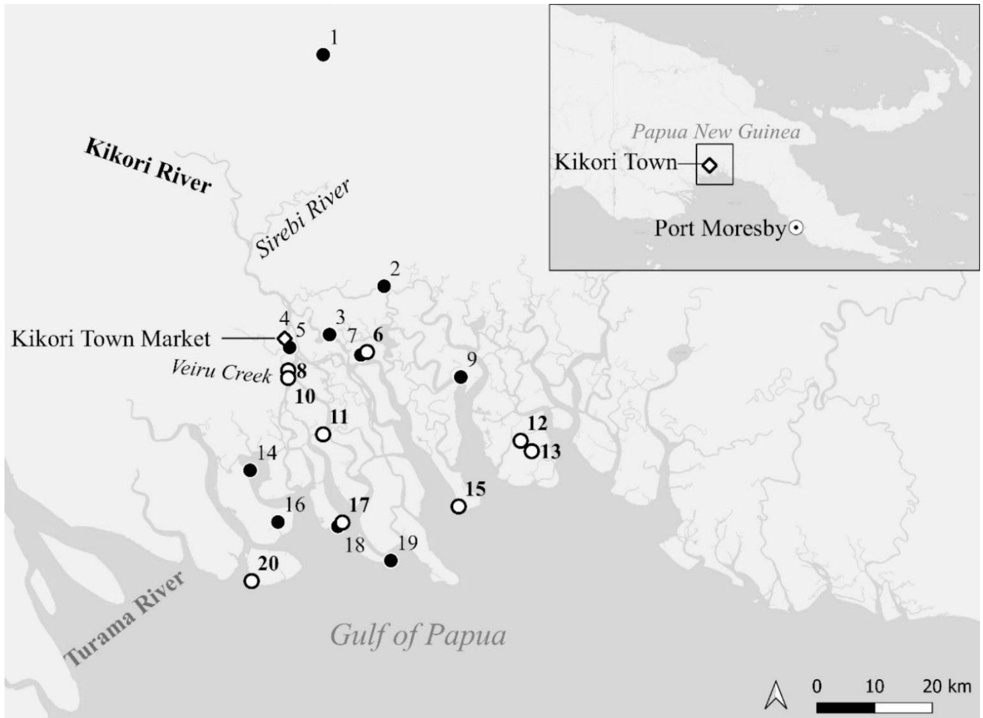

Fig. 1 Source of catch locations for fish recorded at Kikori Town Market. Black dots were locations where market vendors reported capture of the fish they were selling at the time, and white dots were locations where market vendors reported capture of fish they were selling, and were additionally interviewed. The inset map shows the location of Kikori Town relative to Papua New Guinea mainland

Table 2 Abundance, size, and value for each condition of sale for species observed at Kikori Town Market

	Fresh condition				Smoked condition			
Species	n (%)	Length cm range (mean)	Weight kg range (mean)	Value (PGK kg^{-1})	n (%)	Length cm range (mean)	Weight kg range (mean)	Value (PGK kg^{-1})
Acanthopagrus pacificus	3 (100%)	21.3–41.5 (34.7)	0.21–1.56 (1.01)	5.41				
Datnioides campbelli	1 (100%)	23	0.29	6.90				
Eleutheronema tetradactylum	114 (42.7%)	16–42.4 (21.4)	0.03–0.52 (0.07)	11.54	153 (57.3%)	14.7–43.6 (25.3)	0.03–0.34 (0.08)	22.23
Kurtus gulliveri	36 (8.18%)	14.0–36.3 (22.7)	0.03–0.27 (0.09)	5.45	404 (91.8%)	12.5–45.0 (24.9)	0.03–0.22 (0.08)	14.33
Lates calcarifer	2 (100%)	33.6–39.1 (36.4)	0.46–0.67 (0.56)	7.33				
Lutjanus goldiei	1 (100%)	56.4	3.49	14.33				
Lutjanus johnii	2 (100%)	24.5–27.9 (26.2)	0.22–0.29 (0.26)	7.88				
Mugilidae spp.	182 (86.3%)	15.0–25.0 (17.6)	0.06–0.15 (0.08)	5.75	29 (13.7%)	14.0–19.0 (18.5)	0.04–0.06 (0.06)	7.99
Nibea squamosa	65 (54.6%)	16.3–72.3 (35.7)	0.03–3.36 (0.70)	9.47	54 (45.4%)	12.0–46.5 (29.4)	0.03–0.80 (0.17)	16.38
Oreochromis cf. *niloticus*	135 (80.4%)	20.3–45.0 (38.5)	0.09–1.66 (1.00)	6.38	33 (19.6%)	27.6–40.2 (33.4)	0.24–0.44 (0.34)	16.77
Oxyeleotris lineolata	7 (70.0%)	35.6–47.0 (41.0)	0.48–1.10 (0.75)	7.04	3 (30.0%)	18.7 (18.7)	0.07 (0.07)	7.14
Parambassis gulliveri	7 (41.1%)	15.7–30.0 (20.2)	0.05–0.54 (0.18)	8.21	10 (58.8%)	8.5–22.0 (14.90)	0.03–0.07 (0.05)	10.01
Platycephalidae sp.					1 (100%)	36	0.13	15.38
Polydactylus macrochir	5 (18.5%)	39.5–80.0 (60.1)	1.64–5.90 (4.03)	3.57	22 (81.5%)	17.0–34.0 (20.5)	0.09–0.45 (0.36)	
Protonibea diacanthus	2 (40.0%)	41.5	0.61	8.20	3 (60%)	17–21 (20)	0.04 – 0.10 (0.06)	7.60
Scatophagus argus	19 (90.5%)	13.6–22.8 (18.1)	0.10–0.34 (0.17)	7.44	2 (9.5%)	16.7–24.0 (20.4)	0.09–0.22 (0.16)	16.11
Selenotoca multifasciata	12 (100%)	14.8–24.2 (19.5)	0.09–0.30 (0.16)	9.41				9.60
Siluriformes spp.	86 (68.2%)	26.0–57.6 (34.7)	0.04–1.53 (0.35)	6.68	40 (31.8%)	17.5–37.4 (27.0)	0.03–0.31 (0.12)	11.65
Thryssa scratchleyi	1 (16.7%)	24.8	0.11	1.82	5 (83.3%)	21.5–22.0 (21.6)	0.04	15.00
Toxotes chatareus	17 (48.5%)	20.8–30.9 (23.5)	0.10–0.54 (0.23)	8.44	18 (51.4%)	10.5–26.7 (18.9)	0.03–0.19 (0.09)	12.46

were < 100 g (745, 50.5%), which mainly comprised *E. tetradactylum*, *K. gulliveri*, and Mugilidae spp.

The three species attributing most proportionately to the total market value observed (2792.20 PGK), were *Oreochromis* cf. *niloticus* (890.00 PGK, 31.9%), *K. gulliveri* (510.50 PGK, 18.3%), and *E. tetradactylum* (374.90 PGK, 13.4%) (Table 1). Of specimens observed in fresh condition, value per kilogram ranged from 1.82 PGK kg^{-1} (freshwater anchovy *Thryssa scratchleyi*) – 14.33 PGK kg^{-1} (*L. goldiei*). Of specimens observed in preserved condition, value ranged from 7.14 PGK kg^{-1} (sleepy cod *Oxyeleotris lineolata*) – 22.23 PGK kg^{-1} (*E. tetradactylum*) (Table 2). For all species except black jewfish (*Protonibea diacanthus*), market value was higher when preserved compared to fresh, with *K. gulliveri*, *Oreochromis* cf. *niloticus*, and spotted butterfish (*Scatophagus argus*) more than doubling in value when preserved. The largest inflation in value when preserved compared to fresh was observed for *T. scratchleyi* (8.24 times higher). Comparative to native species, *Oreochromis* cf. *niloticus* had the 6th lowest value when fresh (6.38 PGK kg^{-1}), and second highest value when preserved (16.77 PNG kg^{-1}).

Length-weight Relationships

Length-weight relationships were modelled for the four most abundant species (excluding Siluriformes and Mugilidae). Growth was approximately isometric (b = 3) for *N. squamosa* (b = 2.96), and allometric for all other species (Table 3). *Oreochromis* cf. *niloticus* (b = 4.24) exhibited increased body mass with length, while *K. gulliveri* (b = 2.41) and *E. tetradactylum* (b = 2.55) exhibited decreased body mass with length (Fig. 2; Table 3).

Market Vendor Interviews

Eleven interviews were conducted due to time and market vendor availability constraints during the time of market surveys. Kikori Town residents comprised 45% (n = 5) of interviewees, while the remaining 54% (n = 6) of interviewees had traveled from their home villages to sell fish (Fig. 1). Five interviewees identified with Kerewo Tribe, while three identified with Kibiri and Urama Tribes, respectively. In all instances, fishing grounds of interviewees were downstream of Kikori Town (Fig. 1 map references 6, 8, 10–13, 15, 17, and 20). All interviewees except one were women. The age of interviewees ranged from 17 to 46 (mean 29). Five interviewees indicated they have fished or sold fish in the Kikori River for greater than 50% of their lives (mean 48%). Interviewees travelled to the market by motor powered boat (64%), paddle canoe (18%), or by foot (18%).

In response to whether interviewees had observed changes in the ‘types of fish they catch or sell’, 36% (n = 4) answered ‘yes’, all citing the arrival of ‘tilapia’ *Oreochromis* cf. *niloticus*. One interviewee additionally reported recently observing snakehead (*Channa* spp.), locally referred to as “guston”. All 11 interviewees were able to positively identify *Oreochromis* cf. *niloticus* from a photograph. No local language names were reported from interviewees (encompassing Kerewo, Kibiri, or Uruma tribes), with all interviewees referring to *Oreochromis* cf. *niloticus* as ‘tilapia ’. *Oreochromis* cf. *niloticus* was reportedly sold and consumed by all interviewees, with 55% (n = 6) of interviewees indicating that *Oreochromis* cf. *niloticus* was equally or more palatable than native fish, 27% (n = 3) explicitly mentioned that they were less palatable (citing the ‘greasiness’ of the flesh) and 18% (n = 2) did not provide comment as they were unsure.

All market vendors except one said that their fishing methods had remained unchanged since the arrival of *Oreochromis* cf. *niloticus* in the Kikori River. This interviewee mentioned that *Oreochromis* cf. *niloticus* can be quite easy to catch with spear or bow (less capital expenditure and effort compared to gillnet fishing). This interviewee explained that sales from *Oreochromis* cf. *niloticus* exclusively was enough to purchase household items (e.g. sugar, salt, and oil) at the local general store.

When interviewees were asked to express any concerns they had around the consumption or sale of *Oreochromis* cf. *niloticus*, 82% (n = 9) indicated no concerns. One interviewee mentioned that buyers from freshwater communities usually only purchase *Oreochromis* cf. *niloticus* and Siluriformes, as they tend to avoid marine species that they are not familiar with. Another interviewee stated that consumption of *Oreochromis* cf. *niloticus* can result in diarrhea and sickness, due to its ‘greasy’ nature. In response to a different question (regarding palatability) another interviewee explained that her baby becomes sick from consumption

Table 3 Estimated regression parameters for the allometric growth analysis of length weight relationships for the four species with > 30 fresh specimens available. SE, standard error

Species	n	Length range (cm)	Weight range (kg)	Regression parameters			
				a	*b* ± SE		r^2
Kurtus gulliveri	36	14.0-36.3	0.03–0.27	0.00005	2.41	± 0.11	0.93
Eleutheronema tetradactylum	114	16.0-42.4	0.03–0.52	0.00003	2.55	± 0.08	0.90
Oreochromis cf. *niloticus*	135	20.3–45.0	0.13–1.66	0.00002	4.24	± 0.14	0.87
Nibea squamosa	65	16.3–72.3	0.03–3.36	0.00001	2.96	± 0.09	0.94

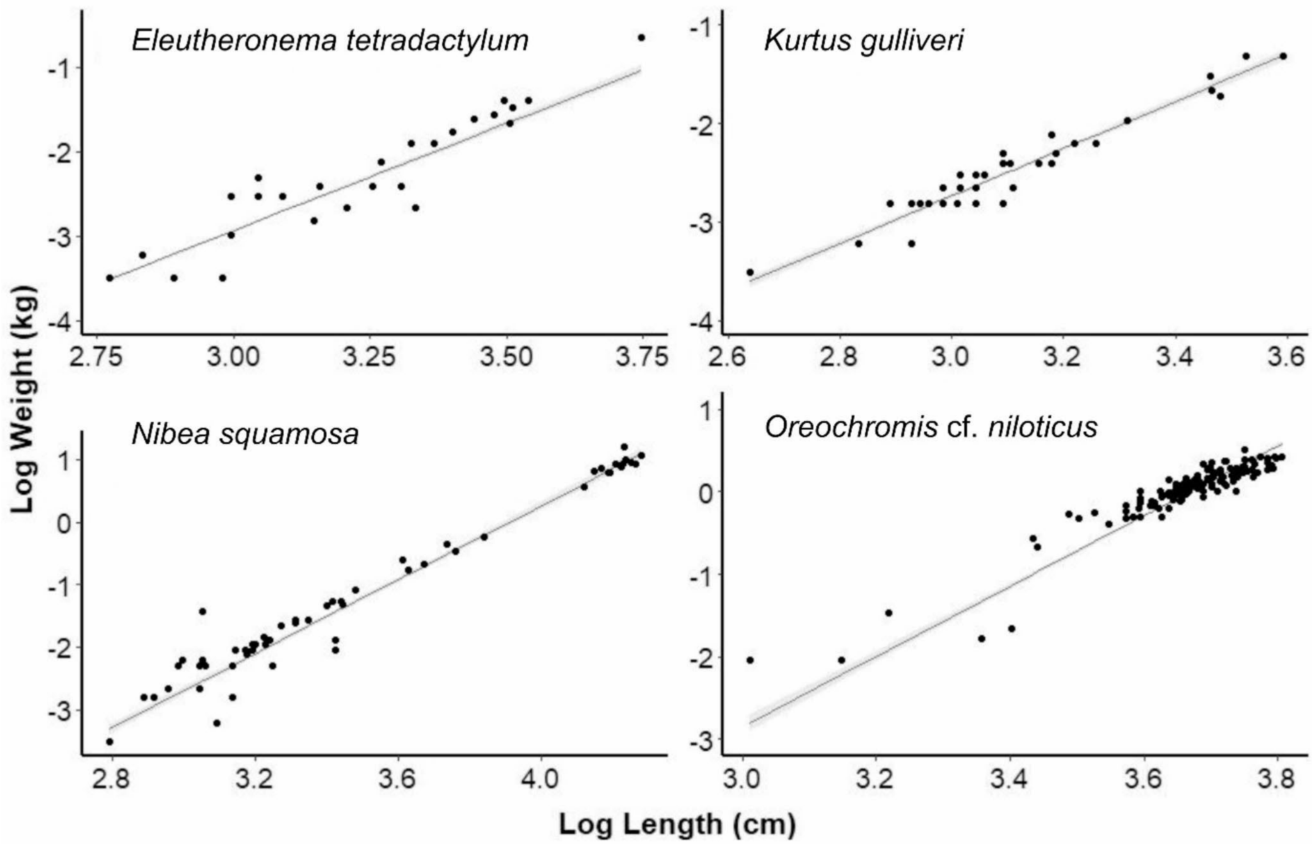

Fig. 2 Log-log transformed length-weight relationship for species with > 30 specimens being sold in fresh condition. Best-fit lines with slope *b* are superimposed, with shaded areas indicating the 95% confidence intervals for *b*. Regression parameters are given in Table 3

of *Oreochromis* cf. *niloticus*, also citing that the ‘greasy’ nature of the flesh was the cause.

When asked about the abundance of native fish in either catches or market sales since the appearance of *Oreochromis* cf. *niloticus*, 36% (n = 4) of vendors indicated that native fish are less common now. Reasons provided for decreased abundance of native fish all pertained to presence of *Oreochromis* cf. *niloticus*. Two interviewees stated that *Oreochromis* cf. *niloticus* ‘chase’ the other fish away, one interviewee stated that *Oreochromis* cf. *niloticus* makes the water ‘greasy’, while the other interviewee did not offer an explanation.

In comparison with the five most abundant large-bodied fish species observed by Eisemberg and Berra (2016), *Oreochromis* cf. *niloticus* was on average the most preferred species to sell by interviewees (Fig. 3. Just over a third (36%) of interviewees placed *Oreochromis* cf. *niloticus* as the most preferred, while its lowest preference rank was fourth. These interviewees cited that *Oreochromis* cf. *niloticus* is easily sold, and popular as a food fish among customers. The least preferred fish species for sale by interviewees was tripletail *Lobotes surinamensis*, closely followed by Siluriformes. Reasons given for the low preference for sale rank of these species included lower eating quality, or that interviewees did not commonly catch these species for sale (e.g. *L. surinamensis*). Despite its abundance in market surveys, only one vendor gave *K. gulliveri* a rank higher than fourth in sale preference.

Larger species (*L. surinamensis*, *L. calcarifer*, and *P. macrochir*) were reported to fetch the highest potential prices at Kikori market. Minimum expected prices were similar between species, excluding barramundi which had a minimum reported value of around 5.00 PGK when sold fresh (Table 4). Prices reported for preserved meat were lower than fresh for all of the large bodied species except *K. gulliveri*, which had equal range values given for fresh or preserved condition. Market vendors generally reported no preference for selling meat as either fresh or preserved for these large bodied species.

Discussion

Market Overview

The present study suggests that *Oreochromis* cf. *niloticus* is widespread and relatively abundant throughout the Kikori

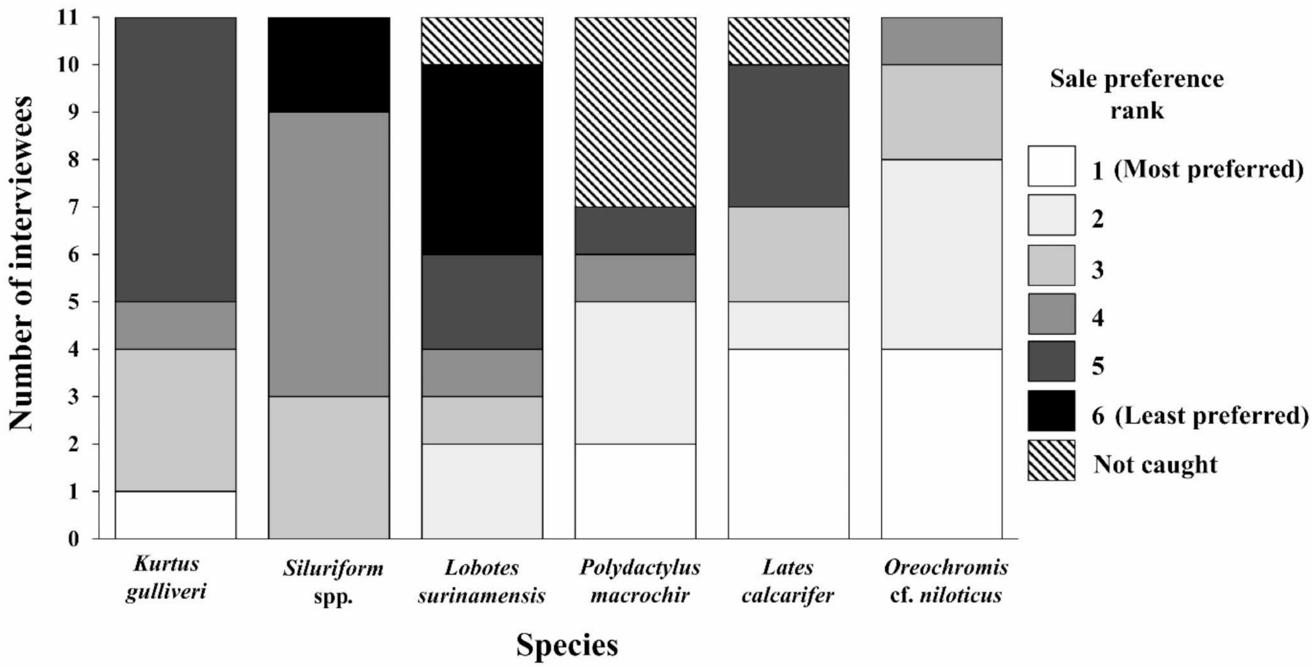

Fig. 3 Sale preference rank values provided by interviewees for the five most abundant larger bodied fish species reported by Eisemberg and Berra (2016) from Kikori Town market, along with tilapia (*Oreochromis* cf. *niloticus*)

Table 4 Price ranges reported by interviewees (*n*) for sale of the six most abundant large-bodied fish species, and the preferred condition for sale. Prices may include both whole specimens or portions. PGK (Papua New Guinea Kina)

Species	*n*	Price range (PGK) Fresh	Price range (PGK) Preserved (smoked or fried)	Preferred condition for sale
Kurtus gulliveri	11	0.2–5	0.2–5	Fresh (20%), Fried (10%), Smoked (20%), No preference (60%)
Siluriform spp.	11	0.5–15	0.3–5	Fresh (10%), Smoked (30%), No preference (60%)
Lobotes surinamensis	10	2–50	0.5–20	Fresh (20%), Smoked (20%), No preference (60%)
Polydactylus macrochir	7	0.2–50	0.2–20	Fresh (29%), Smoked (29%), No preference (42%)
Lates calcarifer	10	5–90	2–25	Fresh (30%), Smoked (20%), No preference (50%)
Oreochromis mossambicus	11	1–15	0.8–8	Fresh (18%), Smoked (27%), No preference (54%)

River. The number of species being sold in the market appears to have largely been maintained since initial observations by Eisemberg and Berra (2016), with only the tripletail *Lobotes surinamensis* (Lobotidae) not being observed in the present study. Several additional native species were also observed presently, i.e., *D. campbelli*, giant glassfish *Parambassis gulliveri*, *L. goldiei*, *L. johnii*, *S. argus*, striped scat *Selenotoca multifaciata*, *P. diacanthus*, *A. pacificus*, and one playtcephalid sp.). The higher number of species observed in the present study compared to Eisemberg and Berra (2016) can likely be contributed to the longer study duration, larger number of landings observed, or broad seasonal patterns and finer scale rainfall and moon phase variations (e.g., Idelberger & Greenwood, 2005). Since observations by Eisemberg and Berra (2016) abundances of each native fish species in fishery landings also does not appear to have changed significantly. The two most common groups of species observed by Eisemberg and Berra (2016) were Siluriformes spp. (18.0%) and *K. gulliveri* (15.6%), which had abundances of 8.6% and 29.9%, respectively, in the present study. This contrasts observations of Smith et al. (2016), who found that native fish species had declined markedly since the introduction of GIFT *O. niloticus* in Lake Kutubu a few years earlier. There are substantial environmental differences (e.g. spatial extent) between Lake Kutubu and the lower Kikori River that would affect the time taken for *Oreochromis* cf. *niloticus* to proliferate. Therefore, abundance and species diversity monitoring in the lower Kikori River should be integrated into future fisheries and environmental planning objectives, as it is likely that the effects of *Oreochromis* cf. *niloticus* on native species have only partially manifested.

A major difference between Eisemberg and Berra (2016) and the present study was a lack of larger bodied species such as *L. surinamensis, L. calcarifer* and *P. macrochir*, and more small-bodied schooling species such as *E. tetradactylum* and *M. cephalu*s. The paucity of larger-bodied species is likely the result of preferential sale to commercial fish buyers that have opened since 2015, between the previous and present studies. These commercial buyers purchase large teleost (mainly *L. calcarifer*, *N. squamosa*, and *P. macrochir*) and elasmobranch species with high meat and dried product value (teleost swim bladder 'fish maw' is the primary product, while 'shark' fin is a supplementary product) directly from small-scale fishers, including from the same communities contributing catch to Kikori Town market in the present study (Grant et al., 2021a, 2022). While reasonably high abundances of *N. squamosa* (8.07%) were observed in the present study, these were mainly small juveniles with meat quantities and swim bladder sizes unlikely to be of commercial interest. Meanwhile, the lack of juvenile *L. calcarifer* may be a symptom of overharvest from the combination of effort between the 'lower value' fishery contributing to sales at Kikori Town market and the higher value fish maw fishery. Effort in the fish maw fishery has expanded rapidly in recent years (Grant et al., 2022), and the lack of juvenile barramundi in the present study indicates the need for stock status assessments for this and other traditionally harvested species.

Oreochromis cf. *niloticus* comprised the largest portion of biomass (40.23%) observed, despite accounting for only 11.40% of the total abundance. This suggests it is providing an important source of protein to local communities. Furthermore, the higher *b* value (> 4) obtained from the length-weight relationship of *Oreochromis* cf. *niloticus* indicates higher body mass compared to the size classes present for native species (Froese, 2006). A limitation of the length-weight relationships performed is that there were clear size class bias's present. However, the values of *b* calculated are representative of size classes that are being sold at the Kikori Town market, therefore these estimates provided are still useful in the context of comparisons for fish being sold and consumed locally. The most robust sample size was obtained for *K. gulliveri*, which had the lowest body mass to length ratio of all species analysed.

Most (52%) of the fish on sale were in a preserved condition (almost exclusively by smoking). However, there was some variance in sale condition between species. For example, 91.8% of *K. gulliveri* were smoked, while only 19.6% of *Oreochromis* cf. *niloticus* were smoked. Smoked fish also generally had higher value, with smoked specimens of both *K. gulliveri* and *Oreochromis* cf. *niloticus* being almost triple the price per kg compared to fresh. These observed prices contradicted responses from market vendors in the interview, where most vendors reported that fresh fish had higher values. It is likely that fresh specimens have a higher potential sale compared to smoked, though a challenge to vendors appears to be retaining freshness and value prior to sale. There are many post-harvest factors that remote small-scale fishers need to consider between catch and sale (Akintola et al., 2022). A major ongoing constraint for coastal and riverine fishers in PNG is a lack of access to refrigeration. For local fishers, this creates logistical difficulties in instances where fish are caught far away from Kikori Town or where low prospective value of daily catch precludes the time or economic expenditure needed to travel to market. For these reasons, sale of preserved fisheries products is often more practical for remote fishers in PNG, as products can be stockpiled to maximise the profitability of market visits (Vieira et al., 2017). An additional advantage to the sale of preserved fish is that unsold product retains value for longer, compared to fresh fish which must be quickly sold before the quality and price reduces (Akintola et al., 2022). The purchase of fresh fish also presents logistical problems for the consumer, as fresh fish in the hot humid climate of lowland PNG must be consumed or smoked soon after sale. The abundance and higher value of preserved fish observed may therefore also indicate greater practicality for consumers.

Market Vendor Interviews

The information gathered from market vendor interviews provides useful insights into the market characteristics and local perception of *Oreochromis* cf. *niloticus*. The reported catch locations of fish observed indicate that fishing communities based in the Kikori River Delta are contributing most of the fish being sold at Kikori Town market. There are a number of reasons why this may be the case: (1) it is likely that there is a greater abundance of larger fish species downstream that have higher potential value, compared to upstream freshwater environments (Haines, 1979; Haines & Stevens, 1983); (2) fishers in the Kikori River Delta are supplied with fishing gears (gillnets and outboard engines) from commercial buyers with interest in fish maw (Grant et al., 2021b), and it is likely that these communities have greater access to fishing gear and possibly spend more time fishing than upstream freshwater communities; and (3) upstream communities have some alternative livelihood options, such as the cultivation of crops (Allen et al., 2005) or employment in the logging industry. Upstream communities also receive financial offsets from logging companies, which may create less need to supplement income through activities such as fishing. Despite most of the fish coming from communities downstream, about half of the interviewees were Kikori Town residents. It appears that individuals of each tribe are fishing in customary waters downstream, and members of the same tribal identity that are based in Kikori Town then sell the catch. The present study also indicted that selling of catch is a fishery role mainly conducted by women. Market operations are one of the small-scale fishery roles typically carried out by women in the South Pacific broadly, along with subsistence fishing (including gleaning) and processing of catch (Harper et al., 2013; Tilley et al., 2021). There is presently a lack of information on gender roles and participation of inland fisheries in PNG, including those in Kikori. This knowledge gap should be considered in future research, as the present lack of understanding risks a lack of consideration of the differing roles of local resources users in future management decisions.

Market vendors mainly expressed a positive attitude toward the sale and consumption of *Oreochromis* cf. *niloticus*. Compared to native fish, *Oreochromis* cf. *niloticus* was reported by most interviewees to be easy to catch and sell, and had comparable or greater palatability to native species. Interviewees stated few concerns around the arrival of *Oreochromis* cf. *niloticus*, and they consistently ranked it as a species of high preference for sale. The most abundant species, *K. gulliveri*, was ranked low for sale preference, which indicates that they are possibly being sold because they are easily caught rather than being particularly valued for consumption. The differences in sale condition between these species (*K. gulliveri* mostly preserved, *Oreochromis* cf. *niloticus* mostly fresh) likely indicate the rate of sale between these two species, as a higher proportion of preserved *Oreochromis* cf. *niloticus* species would be expected if they were not being sold quickly. Although, the differences in body profile between these species may also be a factor, as *K. gulliveri* are thin and elongated, which may assist in preservation. The higher comparative body mass to length ratio of *Oreochromis* cf. *niloticus* compared to *K. gulliveri* is also likely to be a contributing factor to the positive local perception of *Oreochromis* cf. *niloticus* as a food fish, as they offer a higher protein-to-cost ratio for local consumers. Since the development of commercial markets, local consumers appear to have less opportunity to purchase large-bodied species. It appears that *Oreochromis* cf. *niloticus* is filling this void, and is being accepted by locals as a cheap and readily available high quality protein source.

Future Directions for the Kikori River Inland Fishery

Ecosystem services appear to have been maintained despite the establishment of *Oreochromis* cf. *niloticus*. Our preliminary observations indicate that *Oreochromis* cf. *niloticus* is offering local communities social and economic benefits such as access to an easily caught and cheap source of protein. However, it is important to note the relatively recent arrival of *Oreochromis* cf. *niloticus* in the Kikori River (Georges, 2013) and that negative effects on ecosystem services and native species may be yet to occur, as observed in Lake Kutubu (Smith et al., 2016). The Kikori Town market is likely to offer the most cost-effective means to detect future changes considering the logistical difficulties of fisheries and ecological research in remote Papua New Guinea, and greater efforts to survey Kikori Town market are needed at more regular intervals and over longer time periods than Eisemberg and Berra (2016) and the present study. Regular and ongoing monitoring of local market vendor perceptions toward *Oreochromis* cf. *niloticus* will also be important. Local resource users generally have a strong understanding of their local environment, and harnessing local ecological knowledge would be an effective way for early detection of adverse changes in ecosystem services and native species abundance and diversity (e.g., Wilson et al., 2006). For example, four interviewees in the present study indicated that native fish are less common since the arrival of *Oreochromis* cf. *niloticus*, however most interviewees indicated no changes. While it is difficult to quantify these responses, investigation into changes in catch-per-unit-effort would be useful and complimentary measure to local knowledge in informing emerging adverse effects on native species abundance. Furthermore, research to determine the trophic position being occupied by *Oreochromis* cf. *niloticus* would help to inform which species are most at risk from competition.

There may also be opportunities for fisheries managers to explore economic opportunities from the capture and sale of *Oreochromis* cf. *niloticus*. In other regions of Papua New Guinea and the Solomon Islands, tilapia has been purposely introduced to improve local livelihoods through increased food security and improved economic opportunity (e.g., Dudgeon & Smith, 2006; Pickering, 2009). The GIFT strain of *O. niloticus* has increased characteristics of survival, productivity, and nutrition, making it one of the worlds most suited species for tropical aquaculture and inland fisheries in low-income settings (Gupta & Acosta, 2004). While the introduction of *Oreochromis* cf. *niloticus* into the Kikori River itself was not planned by authorities, there is opportunity for the same positive livelihood attributes to be pursued as were intended in other regions. There may also be opportunity to develop export markets for *Oreochromis* cf. *niloticus* out of the Kikori region, as the necessary commercial fish plant infrastructure is already in place, and a highway connecting Kikori Town to domestic markets in more densely populated regions with limited access to fisheries e.g., Semberigi, Southern Highlands Province and Mt Hagen, Western Highlands Province, has recently opened. Indeed, this highway has led to an increased availability of agricultural products in Kikori, which are transported from the Southern Highlands. With informed management and identification of broader markets, it is possible that an *Oreochromis* cf. *niloticus* targeted fishery in the Kikori region could expand economic opportunities for local communities and help alleviate fishing pressure on native species (e.g., Arthur et al., 2010).

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Author Contributions DLR, YA, MIG conceived study idea; DLR, YA, DI, MIG conducted field work; DLR, YA, CE, WW, MIG analyzed the data; DLR, YA, MIG drafted manuscript; all authors critically revised, edited and contributed to the final draft of the manuscript.

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Data Availability The data sets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing Interests The authors declare no competing interests.

Ethics Approval This study was conducted with human ethics approval (H7240) from James Cook University. All market vendors and interviewees consented to participation in this study.

Conflict of Interest The authors declare no conflicts of interest.

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