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Impacts of a fish kill at Lake Kutubu, Papua New Guinea

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Abstract

Lake Kutubu is a tropical freshwater lake which is internationally renowned for its biodiversity, 12 endemic species of fish, wetlands and swamp forests. This study reports on a fish kill and the introduction of exotic species, and assesses impacts on fish stocks and the artisanal fishery. The fish kill, which began in January 2013 and lasted for six months, was characterised by fish pathologies consistent with EUS (epizootic ulcerative syndrome). Sleeper gobies and gudgeons (i.e. *Mogurnda variegata* Nichols, *Mogurnda furva* Allen and Hoese, *Mogurnda kutubuensis* Allen and Hoese, and *Oxyeleotris fimbriata* Weber) had more obvious signs of disease than *Hephaestus adamsoni* Trewavas, *Melanotaenia lacustris* Munro, and *Craterocephalus lacustris* Trewavas. The event coincided with an inflow of a plume of white particulates from the northeast, where hydrocarbon companies carried out extensive horizontal drilling in 2012-13. Six months after the event, the main species caught by fishers were *Cherax papuanus* Holthuis (16 %), *H. adamsoni* (55 %) and *M. lacustris* (28 %), which is different from the mix of species found in previous surveys of 1995 and 1997. The recent fish kill, as well as socio-economic changes, substantially reduced the fish catch and fishing effort. Small-scale fish farmers began raising the GIFT strain of tilapia (*Oreochromis niloticus* Linnaeus) and common carp (*Cyprinus carpio* Linnaeus) in earthen ponds in 2009 and introduced water hyacinth (*Eichhornia crassipes* Mart. Solms) as a food for these fish. Heavy rains in 2010-12 released farmed fish into the lake and in May 2015 fishers report that the fish catch is dominated by tilapia. Improved strategies are required to educate stakeholders, assess fish stocks and protect biodiversity by reducing anthropogenic impacts.

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Introduction

Lake Kutubu (latitude 06 º 25.79 ′ S, longitude 143 º 20.22 ′ E, altitude 808 m) in the Southern Highlands Province of Papua New Guinea (PNG) has been recognised as one of the most pristine, biologically diverse freshwater lakes in the whole of the Asia-Pacific region (D'Cruz, 2008). As evidence, Lake Kutubu was the first subterranean karst wetland type[1] to be added to the Ramsar Classification System by Resolution VI.5 (Ramsar site no. 961). Karst (cave) wetland systems are connected to underground rivers and act as recharge areas when the surrounding water table is low, and as discharge areas when it is too high. Since 1998, Lake Kutubu also has been designated as a Wildlife Management Area (which is the simplest form of protection of an area of land or water, while still retaining full power of landowners to manage their land through an elected committee formed of customary landowners). It has approximately 5,000 ha of open water, 2,000 ha of wetland swamp forest and a catchment of some 76,000 ha, which is mainly tropical rainforest. The lake has at least 12 endemic fish species, the most well-known is the popular aquarium fish, called the Lake Kutubu rainbow fish, *Melanotaenia lacustris* Munro (Coates, 1986). The epilimnion (upper layer of water) of Lake Kutubu is normally 10-25 m in depth and has a stable average temperature of 23 ºC (D. Cruz, 2008). It is characteristically alkaline (pH 8.1) and clear (Secchi transparency of 7-8 m). The epilimnion has high levels of dissolved oxygen because of freshwater algae, *Nitella pseudoflabellata* A. Braun, which grow in the waters at the north and south ends of the lake (Fig. 1). The hypolimnion (lower layer of water) is substantially different to the epilimnion, having lower temperature, lower pH, higher levels of nutrients, lower transparency and very low levels of dissolved oxygen. Recent anthropogenic activity has increased the pressure on fish stocks and biodiversity of Lake Kutubu (D'Cruz, 2008; Imbun and Mondu, 2011). According to the red list of the ICUN (International Union for Conservation of Nature), four species (*Cherax papuanus* Holthuis, *M.*

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lacustris, *Oloplotosus torobo* Allen, and *Hephaestus adamsoni* Trewavas) have vulnerable status, one species (*Craterocephalus lacustris* Trewavas) is endangered, and two species (*Mogurnda variegata* Nichols, *Mogurnda furva* Allen and Hoese) are critically endangered. This project aimed to investigate the current status of the fish stocks in Lake Kutubu.

<<Fig. 1 near here>>

Prior to the discovery of oil near Lake Kutubu in the 1990s, a small-scale artisanal fishery supported between 2,000-3,000 indigenous people, the Foe, who live in the surrounding catchment area of the lake. The use of gill nets was identified as a cause of reduced fish abundance, so in 2000 approximately 500 fishing nets were burned at Lake Kutubu (Imbun and Mondu, 2011). Recent inward migration has increased the local population to over 7,000 and the Foe have been encouraged to construct fish ponds to culture the GIFT (genetically improved farmed tilapia) strain of tilapia (also known as Nile tilapia, *Oreochromis niloticus* Linnaeus 1758) in order to supplement their diet (Anon., 2013). Aquaculture of the GIFT strain of tilapia is rapidly expanding in PNG because the fish breed easily in ponds and feed on plankton blooms (Smith et al., 2007). The GIFT strain is ranked in the top three fish worldwide and production continues to increase (Lim and Webster, 2006).

There have been claims that the artisanal lake fishery has been declining in recent years and that fish kills have been caused by hydrocarbon projects (Cubby, 2009; Weitenberg, 2009; Kuusa, 2013; Mamu, 2013; Wrakuale, 2013). But a recent study attributes the change in fish stocks to overfishing, not to direct impacts on the aquatic habitat by the activities of hydrocarbon projects (Hydrobiology Ltd, 2010). Given these divergent views, this study investigates multiple lines of evidence to examine the circumstances of a recent fish kill and the introduction of exotic species. The study assesses the impacts on the artisanal fishery and fish biodiversity.

Materials and Methods

Fieldwork was conducted at Lake Kutubu in May-June 2013. The status of the artisanal lake fishery was assessed by observing fishers during their normal fishing operations and by collecting data with the help of local community members. A survey provided data on fishing activity for the main fishing areas of the lake (60 % of the lake). Data were collected on the daily fishing effort, daily fishing catch and other notable observations about the fish, including species, size, sexual maturity, feeding behaviour and signs of disease. In May-June 2013, 12 semistructured interviews were conducted with fishers and local representatives with regards to endemic fish species, fish catch, introduced fish species and the history of impacts on the lake. Follow up interviews were conducted by telephone in May 2014 and March 2015.

Fish ponds at fish farms were assessed at three villages: Saraga, Wasemi and Kei Point (Fig. 1). Data were collected on the species of fish, stocking density, feeding regimes, feed types, husbandry, pond sizes and water management. Fish were examined for size, sexual maturity and signs of disease. Six fish farmers were interviewed on the history of their farm and their husbandry techniques.

Results

Information from interviews

Interviews with local community members revealed that fish began dying between December 2012 and January 2013, and that fish mortality was greatest in January to March 2013. Huge numbers of sick and dead fish were seen floating and rotting around the banks of the lake. Fish were described as having red sores, swollen bodies, rotting flesh, ulcers, missing flesh and chemical-like burns. These observations by the interviewees are consistent with television images in January 2013 (Kuusa, 2013). Mortalities declined during 2013 and stopped by the end of 2013. Community members said locals were fearful of unknown pollutants or chemicals in the lake, so they stopped fishing when the fish kill began. Interviewees said that it was the first time that they had seen fish die in such large numbers and with these signs of disease. “It was a new thing”. Their statements implied that EUS (epizootic ulcerative syndrome) or an EUS-like disease had not occurred in Lake Kutubu prior to 2013.

Some of the interviewees said that in previous years they had witnessed “natural” fish kills in cooler months after storms. Turnover “in old times” caused fish to die, but during those events “only bigger fish died” and the lake soon recovered when the smaller fish took over. They said that soft bodied fish (*Mogurnda* spp.) and fish with larger scales were equally affected during “natural” fish kills. On those occasions the water changed colour from clear/green to brown. Their observations of “natural” fish kills are consistent with breakdown in the stratification of the water column and upwelling of water with low oxygen. Interviewees said that the fish kill in 2013 was “different” for many reasons. It occurred in warm wet weather and coincided with the discharge of a plume of white suspended material from the northern inlets, especially Kaimori Creek and Tugibu Creek (Fig. 1). During 2013 the fish with soft bodies were most affected (see

Table 1) and fish with harder bodies, such as sesa'bo (*H. adamsoni*) and korekaebu (*M. lacustris*), were least affected. The crayfish known as gari (*C. papuanus*) was not affected in 2013 and neither were the two farmed species, GIFT strain of tilapia and common carp, *Cyprinus carpio* Linnaeus. The effects of the fish kill on endemic species are summarised in Table 1.

<<Table 1 near here>>

Interviewees said that when fish began dying in 2013, their children, who dived to spear fish and crayfish, complained that their eyes were blood-shot, sore and "felt scratchy". They said that the skin of these children was dusty and dry "like sawdust". One interviewee described the water as having small dots in it "like white Omo" (a brand of washing powder for clothes). The white plume spread within one week through the lake and it remained visible for several weeks. The interviewees claimed that the white plume came from the areas where pipes had been laid by the hydrocarbon project in late 2012 to early 2013. This observation is supported by television images in January 2013 (Kuusa, 2013). The limestone rock had been excavated and several kilometres of piping had been laid to carry oil and gas. One interviewee stated that bentonite clay was used in the process. This is consistent with the statement by ExxonMobil's managing director in PNG, Mr Peter Graham, that horizontal-directional drilling only "uses clay and water" and that the work was disclosed beforehand (Kuusa, 2013). Also, an inspection of sites that had been identified in interviews, revealed that horizontal-directional drilling and burying of pipelines had involved extensive excavations for several kilometers in the catchment of Lake Kutubu. These disturbances were most visible along the gravel road at the north and northeast sides of Lake Kutubu.

Further, interviewees claimed that another fish kill, which occurred about five years beforehand, was similar to the 2013 fish kill and was said to have coincided with the appearance of suspended material and a yellow chemical "like sulphur" that spread on the surface of the lake. Interviewees said that suspended material and a surface layer originated from drilling activity by the hydrocarbon company at Mount Kemenage near Yo'obo and Sama'a River (Fig. 1). Locals claimed the event also caused the death of one child and it was reported in the media (Cubby, 2009; Weitenberg, 2009).

Fishers and community members claimed that when fishing recommenced after the fish kill in 2013, many fish were very scarce (see Table 1). The fish species that traditionally had been a large part of the catch, had disappeared. Interviews in March 2015, found that two years after the fish kill, the most common species caught by fishers was the GIFT strain of tilapia. These fish are caught from canoes by hook and line, by gill net and by diving with a hand spear. Interviewees said that the fish range in size from fingerling to “A4 paper size” (200 mm long). The bait for catching tilapia was mainly “tree grubs and worms”. The catch of crayfish had decreased and one interviewee said that this was because the seagrass had disappeared. The crayfish had “lost their hiding place”. Interviewees, without exception, expressed general frustration about the lack of response to the fish kill by the hydrocarbon companies, NGOs and Government. As of March 2015 they claim that they have been told that findings of the environmental study of the fish kill “are still pending”. We independently examined moribund fish during our field trip and the results are as follows.

Signs of disease and characteristics of the fish kill

Dead and moribund fish were seen floating on the surface and around the edges of the lake in May and June 2013, some 4 months after the peak of the fish kill. The water appeared normal – it had a clear-blue colour and a transparency of more than 5 metres. The observations indicated that the cause of the fish kill had remained active for more than 5 months. The gross pathology indicated that the fish kill was due to an outbreak of EUS (epizootic ulcerative syndrome) which is caused by a fungal pathogen. However, until histopathology is carried out on preserved specimens, it remains a possibility that the fish kill could have been caused by another pathogenic agent. Fish with minor lesions had one or more of the following signs: reddening of the body, red spots or lines of ruptured epithelial tissues and vessels, especially around their eyes (blood-shot eyes) and operculum. Fish with advanced pathology had large necrotic, open ulcers which were usually about 8-10 mm in diameter and these lesions were observed on the face, gills, operculum and body of moribund fish. Examples of six different species of moribund fish are given in Figure 2. The signs of disease were consistent: reddening particularly of the operculum and around the head, swelling of the surface tissues with white or red blotches, and necrotic fins and ulcers.

<<Fig. 2 near here>>

A total of seven different species of fish were observed with presumptive EUS (Table 1). One moribund specimen of a *Mogurnda* sp. (Figure 2E, Table 1) was identified as a *koro* (in Foe) but could not be classified with certainty. Three other species (known to the Foe as *mossa*, *taodobu* and *iragobi*) were not observed during the field trip, and they are now considered scarce according to local community members (Table 1). The most susceptible species appeared to be those with a soft body surface, such as gudgeons and sleeper gobies (mogurndas). These included *M. variegata*, *M. furva*, *Mogurnda kutubuensis* Allen and Hoese, *Oxyeleotris fimbriata* Weber, and the catfish (*O. torobo*). The less susceptible species were *Craterocephalus lacustris* Trewavas, *H. adamsoni*, and *M. lacustris*. The endemic crayfish, *C. papuanus*, known as *gari* to the Foe, was plentiful in May-June and by its appearance and activity, was not adversely affected by the EUS-like outbreak.

Fishing activity in Lake Kutubu

Data were collected on fishing activity in May-June 2013. Women and children fishers use canoes in the daytime to catch fish by hook and line with earthworms and crayfish. They also use canoes to set gill nets (10 – 15 mm mesh) around the shore of the lake at dusk and collect their nets the following morning. An average of seven nets (range of 0 - 11 nets) were set between 4pm and 6 pm each evening in the survey area. The number of fishing canoes in the survey area peaked at seven canoes in the morning and evening (Fig. 3). Fishing activity was similar for all days of the week, except on Sunday mornings when religious services were held. The number of canoes on the lake temporarily decreased whenever there was a strong wind or heavy rain.
<<Fig. 3 near here>>

The average number of fishers in the survey area was 20 per day and the average catch per fisher was 1.0 ± 0.3 kg of *H. adamsoni*, 0.5 ± 0.2 kg of *M. lacustris* and 0.3 ± 0.1 kg of crayfish, plus some minor catches of other fish. The total fish catch averaged 36 kg per day or 13,000 kg pa in the survey area, which covered 60 % of Lake Kutubu. Based on a preliminary boat survey at the start of the study, we assumed that the survey area was representative of the whole lake. This is a reasonable assumption because the location of villages is known (see Fig. 1), and fishing activity originates from these sites and fishing intensity was distributed fairly evenly around the lake. Based on this assumption, the catch in the remaining 40 % of Lake Kutubu is estimated to be similar to the catch in the survey area, and the total catch for Lake Kutubu was approximately 60 kg per day by 33 fishers during the period of the survey. This extrapolates to an annual catch of approximately 22,000 kg. Abandoned and unused fishing nets were observed hanging from branches along the shoreline of the lake and fishers commented in May-June 2013 that many Foe had stopped fishing because of the fish kills.

Most fishers were young girls and the number of fishers in each canoe averaged two people. For example, a 10 year old fisher was surveyed at 11:30 am when she was returning home. That morning the young girl had retrieved her net, caught 1.2 kg of crayfish, *C. papuanus*, by diving, and caught fish by hook and line while caring for her six year old sister in the canoe. She had 13 *H. adamsoni* (2.5 kg) and 32 *M. lacustris* (1.2 kg) which she had mainly caught with her gill net. The catch of crayfish and fish was for her family's meals. In another example, a 45 year old female fisher caught *H. adamsoni* by gill net which was set at 6:30 pm and retrieved the next morning at 9:30 am. She caught 13 healthy fish averaging 200 mm and weighing a total of 2 kg. All male and female fish were sexually mature, suggesting that *H. adamsoni* had overcome the impacts of the fish kill.

Crayfish, *C. papuanus*, were commonly observed on the sandy shallow banks around the south end of the lake, with a density of approximately 1 per 25 m^2. Also water snails were common on the sandy banks and amongst *N. pseudoflabellata* and other water plants. *C. lacustris* and *M. lacustris* were plentiful near the limestone walls of the lake, particularly beneath overhanging trees where they could be seen preying upon insects.

Fish farming in earthen ponds

According to interviewees, fish farming began at Moro, which is several kilometres from Lake Kutubu, when Chevron, an international oil company, constructed demonstration fish ponds in the 1990s (Fig. 1). The ponds were stocked with common carp and two species of tilapia, *Tilapia rendalli* Boulenger and *Oreochromis mossambicus* W. K. H. Peters. In 1995, heavy rains washed the fish into creeks, which flow into Soro River and the Kikori River catchment. Locals soon started catching these fish with spears and nets at Kei Point, Soro and the outlets to the creeks (Fig. 1). More recently, fish farming began at Lake Kutubu in about 2009 when Foe villagers constructed fish ponds on the edges of the lake and stocked the ponds with fingerlings of GIFT strain of tilapia and common carp, which they transported from other areas of the highlands of PNG.

There is a total of 50 fish farms in the five villages around the lake with 2 to 5 ponds per farm. Ponds were dug by shovel and each pond is typically only 2 - 3 m square and 0.30 - 0.45 m deep. All farms had the GIFT strain of tilapia and it clearly reproduces easily under local conditions. A few farms had common carp and one farmer claimed that an exotic fish called *besta* (snow trout or *Schizothorax richardsonii* J.E. Gray) had been brought to Lake Kutubu from

Yonki reservoir. Most farmers had started fish farming only two years beforehand and no farmer had any training. The methods of husbandry were very basic: ponds were small, aeration devices were not used, food was often not used and the water level in ponds was maintained by seepage or the ground water table. For example, three farms at Saraga each had two to four small ponds measuring 2 m x 2 m, and fish were not fed. At Wasemi Island, one farm had six ponds measuring 3 m x 4 m. This farm was the most developed, however the farmer used an expensive, uneconomic diet of 100 % fishmeal. The ponds were overstocked with GIFT fish at various ages and fish were gaping at the surface for air, indicating low dissolved oxygen and overstocking. Breeding was uncontrolled. There were also a few orange carp (Cantonese strain) in each pond. The carp were large enough to spawn in about six months. At Kei Point, a farmer integrated fish ponds with ducks and chickens. Water hyacinth, *Eichhornia crassipes* Mart. Solms, was observed in ponds at all fish farms, and farmers stated that it had been introduced recently from Port Moresby as a food for fish. Heavy rains in 2010, 2011 and 2012 washed out many of the fish ponds, releasing fish into the lake.

Discussion

What caused the fish kill of 2013?

The study found that it was most likely that a prolonged outbreak of a pathogen that caused EUS disease was responsible for the widespread fish kill of Lake Kutubu in 2013. Figure 2 illustrates clinical signs of disease that were typical of endemic species of Lake Kutubu. EUS is a highly invasive disease that is caused by an invading fungus, *Aphanomyces* that causes necrotic changes in the skin and muscle tissue, ultimately leading to the formation of dermal ulcers (Callinan et al., 1989; Fraser et al., 1992; Mohan and Shakar, 1995; Lilley et al., 1997). EUS was first reported in 1971 at Japanese fish farms by Egusa and Masuda (1971) in ayu (*Plecoglossus altivelis* Temminck and Schlegel). Since then the disease has spread throughout the Asia-Pacific and, although EUS has not been previously reported for Lake Kutubu, it has occurred in the nearby Purari River and elsewhere in PNG (Haines, 1983; Coates et al., 1989). In the Asia-Pacific, EUS outbreaks are seasonal events which appear to coincide with heavy rainfall and deterioration in water quality parameters that include increased turbidity, lowering of pH, reduced salinity and reduced water temperature (Callinan et al., 1995; Chinabut et al., 1995; Vishwanath et al., 1997; Pathiratne and Jayasinghe, 2001; Lilley and Roberts, 2003; Choongo et al., 2009). The fish kill at Lake Kutubu also appeared to be associated with a deterioration in water quality.

Anecdotal accounts from local fishers indicate that the onset of the fish kill in Lake Kutubu coincided with heavy rains and an inflow of a white plume of suspended particulates, and the claim is consistent with media reports and television images in early 2013 (Kuusa, 2013; Mamu, 2013; Wrakuale, 2013). The plume originated from the northern and eastern side of the lake where limestone had been disturbed by the laying of several kilometres of pipeline within the catchment of Lake Kutubu (Fig. 1). The managing director of ExxonMobil in PNG, Mr Peter Graham, stated that horizontal-directional drilling had been carried out within 2 km of the lake and that clay had been used in the process, but he said that he was "at a loss" to see how such activity could cause a fish kill (Kuusa, 2013). The release of clay from excavations is unlikely to have caused ulcers or any direct toxic effect on fish in Lake Kutubu. Instead, the most straightforward explanation for some of the events of 2013 is that inflow of clay and excavated materials caused an increase in turbidity, shading and cooling of the epilimnion at the northern end of the lake. The appearance of suspended white powder in the water column "like Omo" and "sawdust" on the skin of children who swam in the lake, are both consistent with the presence of suspended clay. These changes in the lake may have reduced the stratification and caused an upwelling of anoxic, acidic waters from the hypolimnion. However, none of the interviewees mentioned a cooling of the water and our study could not find any direct evidence for a turnover of the lake. Nevertheless, the changes in water quality that have been described could have created conditions that were conducive for the outbreak of EUS-like disease. Environmental consultants and officers who collected samples in early 2013 (Imbun et al., 2013), may shed light on the link when their measurements and findings are published.

Status of native fish stocks at Lake Kutubu

As recently as 2011, the artisanal fishery in the lake was quite active. Of 137 people who were interviewed, 44 % reported eating some fish in their last meal, and 49 % said that they went fishing every day (Imbun and Mondu, 2011). In contrast in mid-2013, six months after the onset of the EUS outbreak, the number of fishers was dramatically lower (Figure 3). Interviews with the local communities show that this was because of the rapid decline in fish numbers of many species (Table 1), as well as their fear of eating diseased fish. Most recent interviews in 2015 reveal that fish catches are dominated by the GIFT strain of tilapia and that endemic species are rarely caught. Even the crayfish, *C. papuanus*, which emerged unaffected by the EUS outbreak, is now threatened by the loss of habitat due to the abundance of the GIFT strain of tilapia. These findings suggest that ICUN's red list of fish species at Kutubu species is now an underestimate of the threats posed to endemic fish stocks. Of the four species listed as vulnerable, *O. torobo* suffered high impact by the fish kill and *C. papuanus* has diminished subsequently due to invasive fish. The endangered species, *C. lacustris*, experienced medium impact, and the two critically endangered species, *M. variegata* and *M. furva*, experienced high impact. While the stocks of some species of fish have begun to recover from the fish kill, most notably *H. adamsoni*, *C. lacustris*, and *M. lacustris* (Table 1), the gross pathology of the sleeper gobies and gudgeons, as illustrated in Figure 2, indicates that most fish species may have suffered long-term effects due to the outbreak of EUS and related pathology. At least three species of endemic fish were not observed and locals stated that some species are very rare now (Table 1).

The study found that the total catch for all fishers in May-June was of the order of 60 kg per day and by extrapolation, the annual fish catch was approximately 22,000 kg. Given that the study was carried out over a short period, work is planned to further assess the situation. Nevertheless, the findings can be compared to the results of a program that monitored the fish catch between 1995 and 1997 (D'Cruz, 2008). The total annual catch was estimated to be 70,100 kg, which is more than 5 times larger than the current catch. On average 111 people were engaged in fishing then, compared to 33 fishers in 2013. It appears that, from the recent findings of Imbun et al. (2015), many fishers have given up and turned to other socio-economic activities.

The main species caught by fishers in 1995-1997 were *C. papuanus* (33 %), *H. adamsoni* (23 %), *O. fimbriata* (22 %), *M. kutubuensis* (10 %) and *O. torobo* (4 %) (D'Cruz, 2008). In contrast, 4 months after the peak of the fish kill, the main species were *C. papuanus* (16 %), *H. adamsoni* (55 %) and *M. lacustris* (28 %). Some species are no longer caught (e.g. *O. fimbriata*, *M. kutubuensis*), while other species are caught in larger quantities than in previous times (e.g. *M. lacustris*). And two years after the fish kill the GIFT strain of tilapia has become the dominant species in the fish catch. These findings indicate that the native fish stocks at Lake Kutubu are under enormous threat. A recent study attributed the change in fish stocks to overfishing and not to direct impacts on the aquatic habitat by the activities of hydrocarbon projects (Hydrobiology Ltd, 2010). In contrast, our more recent findings suggest that the threats are not limited to those two anthropogenic activities. The arrival of pathogenic disease and the introduction of invasive species, as discussed below, are two new threats to the biodiversity of

Lake Kutubu. Ultimately, the data suggest that fish biodiversity is showing substantial signs of anthropogenic pressure and that the situation needs to be carefully researched and managed.

Introduced species and fish farming at Lake Kutubu

The study confirms that exotic species of fish (tilapia and common carp) have been introduced to Lake Kutubu at various times since the 1990s. These invasive species were introduced to Lake Kutubu to allow local farmers to improve their food security and fish farming has been encouraged for many decades in PNG by government administrations and overseas aid agencies (Smith, 2007). So far more than 25 exotic fish species have been introduced to the highlands and northern rivers of PNG, mainly through fish stock enhancement programs (Dudgeon and Smith, 2006; Smith and Mufuape, 2007).These programs were encouraged because it was argued that the evolutionary history of PNG caused the water bodies on the northern side of the Owen Stanley Range to have lower fish biodiversity than the southern side (Coates, 1986; Coates, 1990).

The first program funded by the United Nations Food and Agricultural Organisation (FAO) was called the Sepik River fish stock enhancement project (SRFSEP, FAO Project: PNG/85/001). It introduced *T. rendalli* (red-breasted tilapia) to the Sepik River System in the early 1990s (Zweiton, 1990; FAO, 1993). FAO followed up in the mid-1990s with a larger project, FISHAID (FAO project: PNG/93/007), which introduced the following seven exotic species of fish to the river catchments of the Ramu River, Sepik River and Yonki Reservoir (Visser, 1996), specifically: *S. richardsonii*, *Osphronemus goramy* Lacépède, *Puntius gonionotus* Bleeker, *Tor putitora* Hamilton, *Acrossocheilus hexagonolepis* McClelland, *Prochilodus marggravii* Walbaum, and *Piaractus brachypomus* Cuvier (also known as *Colossoma bidens*). The most recent introduction was by the Japan International Cooperation Agency (JICA) in May, 1999, when 168 broodstock of the genetically improved hybrid of *O. niloticus* (GIFT strain of tilapia) were brought to the quarantine facilities of the Highlands Aquaculture Development Centre (HAQDEC) in Eastern Highlands Province (Apaise, 2002 in Smith, 2007). The first fingerlings of GIFT fish (also known as *supa* in PNG) were provided to farmers in the highlands in May, 2002 and since then it has become the most commonly farmed fish species in PNG because, unlike common carp, it reproduces easily in fish ponds (Smith et al., 2007).

Some introduced species of fish are providing socio-economic benefits for communities and fish farmers in the highlands and the northern side of PNG (Dudgeon and Smith, 2006;

Smith, 2007; Goitom, 2010). However, some species are of concern for humans and for biodiversity. For example, the snow trout, *S. richardsonii*, is of particular concern because it causes vomiting when eaten and may have caused death in children (Smith and Mufuape, 2007). It is now widespread and abundant throughout the rivers of the highlands of PNG and according to interviews with the Foe, it is also present in Lake Kutubu. It seems that the various internationally-funded fish stock enhancement programs did not adequately consider the possibility and consequences of people transporting fish from the highlands to the southern rivers. As a result, today the precious biodiversity of Lake Kutubu and the Kikori River catchment, plus other southern rivers, is being impacted by species that were introduced by international aid organizations and further disseminated by villagers. These exotic species may also be vectors in the spread of EUS and other disease.

Farmers in the Southern Highlands are currently being encouraged to grow the GIFT strain of tilapia in fish ponds (Anon., 2013). At Lake Kutubu the fish ponds are located at the edge of the lake and are very susceptible to flooding, with the consequent transfer of exotic fish into the lake and this has already occurred in recent years. The study found that fish farming is not economically viable at Lake Kutubu because farmers have not been trained, they do not have husbandry skills, they do not have locally available fish feed, and their ponds are too small. Also, any attempt to farm endemic species rather than introduced species is not likely to be productive because the normal habitat of endemic fish is very different to that of a fish pond, especially in terms of turbidity, pH, dissolved oxygen, and food. Most indigenous fish are carnivores while carp and tilapia are omnivores. In short, programs which encourage fish farming at Lake Kutubu are beset with difficulties of sustainability and management.

Concluding remarks

The study contributes to research knowledge of Lake Kutubu by identifying fish species with the names used by the Foe and photographs (Fig. 2) have been taken of the species (Table 1). The photographs and identification of species support the information provided in earlier publications (Allen, 1985; Allen and Hoese, 1986). This approach should improve communication with locals, stakeholders and research scientists in future research at Lake Kutubu. The study concludes that the most likely direct cause of the 2013 fish kill at Lake Kutubu was an outbreak of EUS. The onset of the event coincided with plumes of suspended material which caused increased turbidity and related deterioration in water quality. This event may have sufficiently stressed the fish community. Natural destratification of Lake Kutubu has occurred in the past, but the study finds that the recent event at Lake Kutubu was different and has been more devastating for the fish stocks and artisanal fishery. Local community members stated that they had not seen a similar event and EUS has not been previously reported for Lake Kutubu. The recent introduction of exotic fish species and water hyacinth may have assisted in introducing EUS to the lake and nearby waters. The substantial changes in fish stocks and biodiversity have occurred in a period when many are benefiting from projects at Lake Kutubu. The most notable beneficiaries are hydrocarbon companies, the World Wildlife Fund for Nature (WWF), environmental agencies, NGOs and government bodies. As it stands, various groups operating in Lake Kutubu and the Kikori Basin have received from the Kutubu hydrocarbon projects funds that should target sustainability and which have been in excess of USD 1 million annually for more than 20 years (Imbun and Mondu, 2011). Environmental consulting groups have had the task of developing the Kikori Catchment Integrated Development Project (KICDP) and using funds to improve educational activities, to raise community awareness, to employ consultants to survey the environment, as well as to manage and promote community-based enterprises. However, our independently funded study found that these programs and activities do not appear to have built technical capacity and have not enabled local communities to acquire skills in environmental monitoring and management. The 2013 fish kill was reported by the Foe people, however they express frustration because of denials or procrastination by those bodies that are capable of over-seeing the health of the lake. The study concludes that there is a clear need for education of all stakeholders to improve the awareness of threats to fish stocks at Lake Kutubu, and to implement improved strategies to monitor and minimise anthropogenic impacts on biodiversity.

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Table 1. The effects of the 2013 fish kill on endemic species of fish and crayfish. The level of impact (column 5) is based on information relayed to authors during interviews. Four rare species of fish (known as *dama-anugu*, *mossa*, *taodobu* and *iragobi*) were described in interviews but not observed by us during the fieldwork.

Species name	Local name of Foe	Importance to Foe	Size (mm)	Impact of fish kill
C. lacustris (Kutubu hardyhead)	*dare*	medium	100	medium
M. kutubuensis (Lake Kutubu mogurnda)	*anagu*	high	100	high
Mogurnda sp. (not identified – see Fig. 2E)	*koro*	medium	100	high
O. fimbriata (fimbriate gudgeon)	*nafa*	high	150	high
M. furva (black mogurnda)	*kanawabo*	medium	100	high
M. variegata (variegated mogurnda)	*serekade*	high	100	high
O. torobo (Kutubu tandan or catfish)	*dorobo*	rare (over-fished)	500	high
H. adamsoni (Adamson's grunter)	*sesa'abo*	high	250	low
M. lacustris (Lake Kutubu rainbow fish)	*korekaebu*	medium	100	low
C. papuanus (Kutubu crayfish)	*gari*	high	80	nil
Mogurnda sp. (blue, like *M. kutubuensis*)	*dama-anugu*	high	100	high
Mogurnda sp. (grey with white spots)	*mossa*	medium	100	high
Unknown (like *M. lacustris*, red and blue)	*taodobu*	medium	100	high
Unknown (yellow and white)	*iragobi*	high	100	high

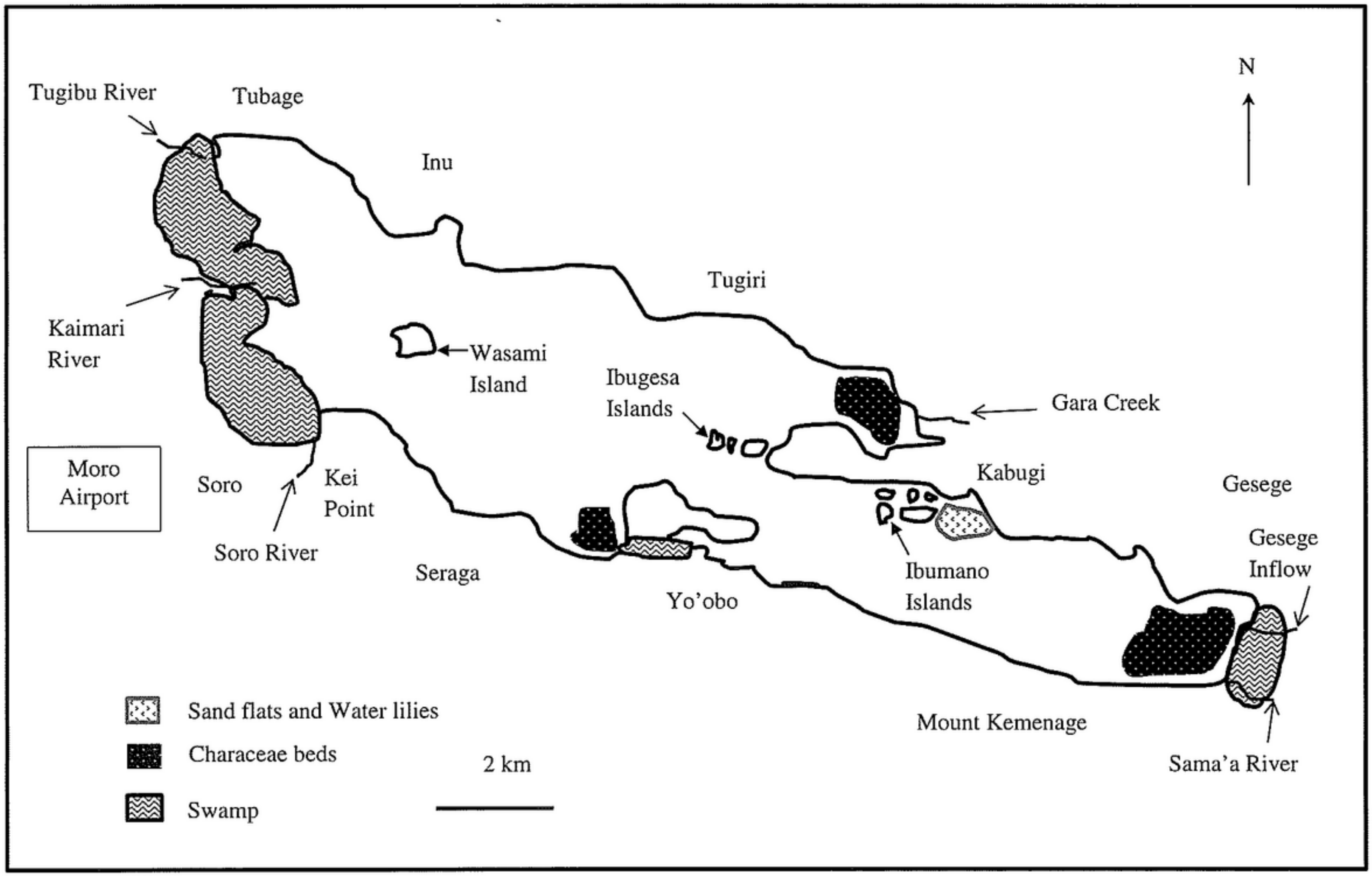

Figure 1. A map of Lake Kutubu which shows the location of the main villages and key habitats. The map was prepared with the assistance of Mr Francis Herman of Lake Kutubu.

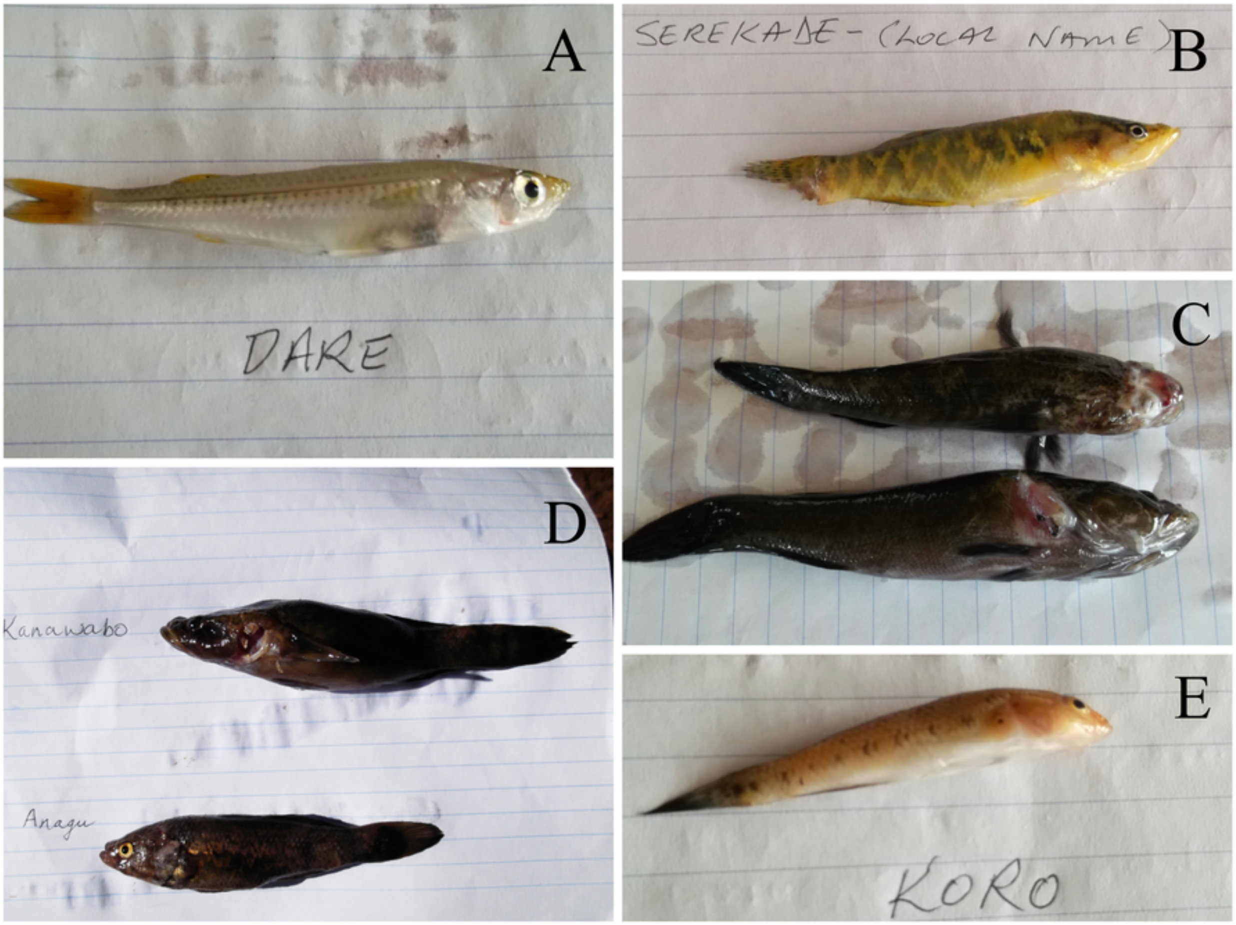

Figure 2. Images of moribund fish species collected in May-June 2013. A) *C. lacustris* (*dare* to the Foe) exhibiting red lines around the operculum and head, plus the body has slightly swollen regions. B) *M. variegata* (*serekade*) exhibiting a necrotic caudal fin, plus swelling and redness of the body, head and operculum. C) Two specimens of *O. fimbriata* (*nafa*) have well-developed ulcers around the head, causing blindness in the upper fish and loss of pectoral fin in the lower fish. Both fish also have white blotches and swelling to the body. D) *M. furva* (*kanawabo*), upper fish, exhibiting a necrotic ulcer on the operculum, plus redness and white blotches and swelling to the body. *M. kutubuensis* (*anagu*), lower fish, with redness and white blotches and swelling to the body. E) *Mogurnda* sp. (*koro*) exhibiting reddening around the head, operculum and body. All fish were collected and identified with the help of Mr Kone Herman. (Scale: lines are 8mm apart.)

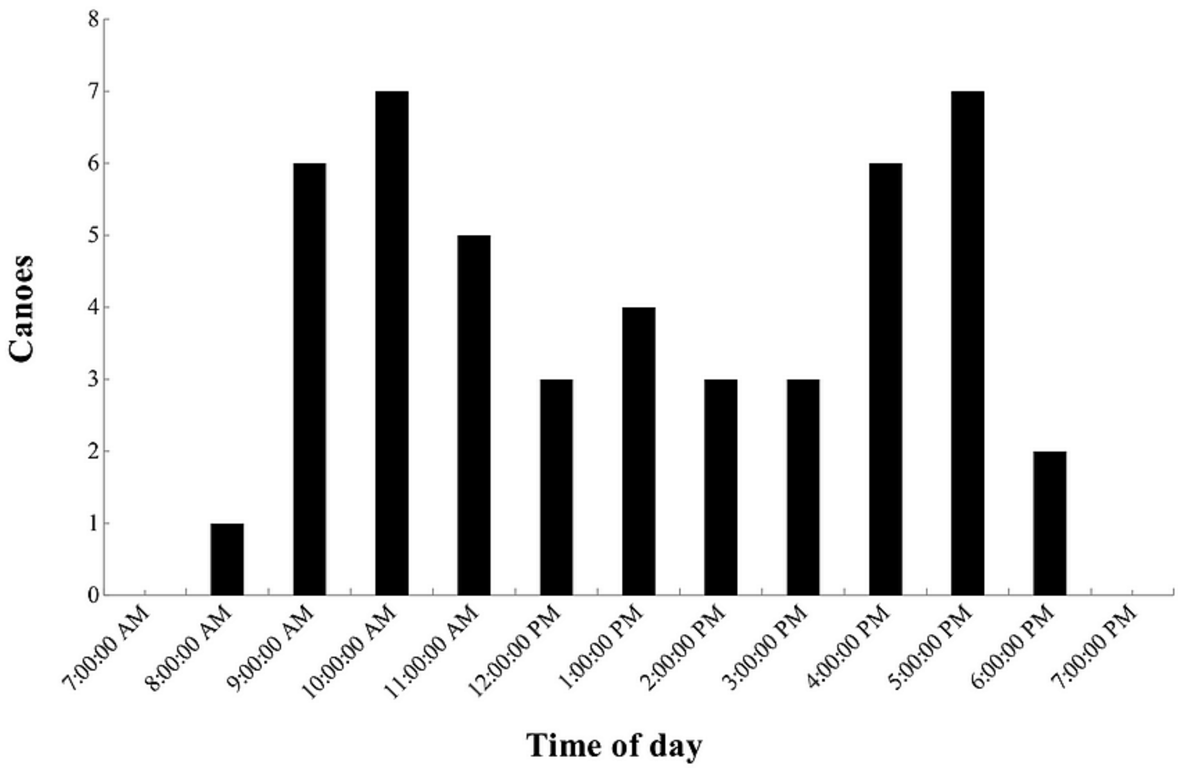

Figure 3. The average number of fishing canoes observed on each hour of the day at Lake Kutubu. Data collected in May-June 2013.

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