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An integrated evaluation of mangrove health and ecosystem value to local inhabitants: a blended ecological and sociological approach

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Abstract

In Fiji, as in other Pacific Islands, mangroves provide substantial resources to local indigenous peoples. These resources include fuelwood, timber, food, and natural medicines. Despite this, Fijian mangroves are still lost or degraded by tropical cyclones, rising tides, tourism development, agriculture, and major construction. To gauge the future health of Fijian mangroves, and their value to local populations, it will be necessary to perform both ecological and sociological surveys to initiate long term monitoring programs. This study comprised detailed botanical and soil analyses of the Nasilai River mangrove forests in the Rewa region of Viti Levu, the largest Fijian island. As part of this study we interviewed local villagers to obtain information about their use of mangroves, their knowledge of sustainable management, and the risks related to climate change. In terms of flora, 28 species of trees and ferns were recorded, with Rhizophora and Bruguiera gymnorhiza dominating, which is typical for mangroves in this area. Similarly, soil physico-chemical properties, such as salinity, pH, nitrogen, and phosphorous were all within expected ranges. Local villagers obtained multiple benefits from the mangroves, such as timber, firewood, medicines, dyes, fruits, and marine shellfish. It appeared that mangrove degradation near to the villages was primarily due to human activities such as over-harvesting, bark removal, and dumping of domestic waste, rather than from climate change effects. Additionally, tree species such as lemons, guava, and papaya, proliferated in sites near human habitation, thus reducing mangrove floral integrity of these areas.

Most villagers were aware of sustainable practices relating to mangrove harvesting, and of threats due to climate change. However, only one of two villages surveyed had experienced formal training in climate change awareness. This study provides essential baseline ethno-biological data for comparison with future studies that will enable any changes in flora, soil properties, damage by climate change, or intensification of local harvesting to be ascertained.

Keywords: ecosystem services; ethno-biology; Fiji; mangrove; Pacific; Rewa Delta

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* Suchindra Dayal's findings for this paper were when she was affiliated with The University of the South Pacific as a Masters student. She has since graduated.

Introduction

Mangrove forests are distinctive ecosystems found in coastal regions of the tropics and sub-tropical regions. Mangroves are under threat due to the consequences of global climate change such as sea-level rise, coastal erosion, and changes in precipitation patterns that modify soil salinity and nutrient distribution (Agrawal et al., 2003; Nunn, 2013; Alongi, 2015; Ghosh, Kumar and Roy 2016; Ward et al., 2016), and from multiple anthropogenic activities such as direct removal of materials, marine and terrestrial pollution, and eutrophication due to nutrient leaching from farmland (Smith, 1996; Spalding, Mami and Lorna, 2010). Additionally, mangrove forests face threats of direct clearance in order to create land for domestic dwellings, tourism amenities, and for large-scale infrastructure such as roads and bridges (Agrawal et al., 2003; Nunn, 2013; Alongi, 2015; Ghosh, Kumar and Roy 2016; Cameron et al., 2021b).

Like other forests, mangroves provide numerous ecosystem services, some of which are of international benefit such as carbon sequestration and augmentation of global biodiversity. On a local scale, mangroves offer multiple benefits, such as direct provision of timber, firewood, fruits and dyes, a nursery environment for fish species, and habitat for other harvestable food sources such as molluscs and crustaceans (Alongi, 2002; Nagelkerken et al., 2008; Haynes, 2011; Alongi, 2015; Romañach et al., 2018; Pearson, Mcnamara and Nunn, 2019). Mangroves also act as a form of natural coastal protection, stabilising shorelines and preventing erosion, and providing a physical buffer against storm tides, tropical cyclones, and water surges (Lugo and Snedaker, 1974; Alongi, 2008; Giri et al., 2008; Marois and Mitsch, 2015; Cameron et al., 2021b). Ecologically, the detritus from mangroves provides nutrients for marine organisms, and therefore contributes to nutrient transfer from terrestrial to marine ecosystems, a process that integrates mangroves into other coastal food webs such as those based on seagrass and coral reefs (Guannel et al., 2016). Finally, mangroves can provide direct economic benefits by activities such as ecotourism and recreation, which, if managed sustainably, encourage the preservation of the forest and conservation of local biodiversity (Pearson, Mcnamara and Nunn, 2019; Spalding and Parrett, 2019).

Around 3% of global mangrove systems are in the Pacific Ocean, with the main stands occurring in Papua New Guinea, followed by the Solomon Islands, Fiji, New Caledonia, and Vanuatu (Gilman et al., 2006; Raga, 2006; Bhattarai and Giri, 2011). Fijian mangrove forests are thought to cover a total area of approximately 435 km^2, although recently Cameron et al. (2021b) have suggested this could be as high as 650 km^2. The largest patches of Fijian mangroves occur around the islands of Viti Levu and Vanua Levu which, together, contain around 90% of Fiji's mangroves (MMC, 2013; Ellison, 2014). In Fiji, as in other Pacific Islands, mangroves are recognised as significant resources with respect to the traditional lifestyles of indigenous peoples, providing resources such as fuelwood, construction materials, food, medicines, natural dyes, and ceremonial commodities such as flowers for garlands (Thaman et al., 2005). Nevertheless, as in many other mangrove systems, the Fijian mangroves are exposed to several natural and anthropogenic detrimental factors, such as tropical cyclones, rising tides, more frequent extreme weather events, tourism development, agriculture, and construction. Where human habitation is close to, or within, the forests, over exploitation of mangrove resources can be evident on a local scale, with degradation occurring due to over harvesting of timber, the presence of non-native or non-mangrove plant species, dumping of domestic waste, and large amounts of plastic waste deposited along river channels and by tides (Fiji Government, 2018; Cameron et al., 2021a; Cameron et al., 2021b).

Mangrove ecosystems are therefore, of considerable importance to the Fijian economy, social structure, climate change mitigation, and for their contributions to local and global biodiversity. Consequently, there have been regular reviews of the state of Fijian mangroves, and recommendations on how these resources can be preserved, managed, and used in a sustainable manner (Cameron et al., 2021a; Cameron et al., 2021b). In 1985, Watling (1985) published a Mangrove Management Plan for Fiji, which was followed by a report by Lal (1990) who described historical mangrove losses. Subsequently, The International Union for the Conservation of Nature (IUCN) funded a study in Nasilai region of Viti Levu as part of the Oceania project "Mangrove Ecosystem for Climate Change and the Livelihoods" (MESCAL project) (Waqa-Sakiti et al., 2013), and five years later a government report recognized mangroves as a Fijian conservation priority (Fiji Government, 2018). The MESCAL report presented the finding of Rewa River mangroves. The team conducted survey of area's biodiversity (flora, herpetofauna, avifauna, terrestrial insects, freshwater fish, invasive species), socio-economic assessment and archaeological survey (Waqa-Sakiti et al., 2013). The botanical survey identified the principal vegetation type in the MESCAL selected site, it described the forest/habitat types, it identified the key mangrove species and assess the level of disturbance in the different forest/habitat types. More recently, Cameron et al (2021a, 2021b) published the results of extensive surveys of Fijian mangroves with respect to carbon stocks, botanical composition, and drivers of mangrove loss and degradation. These latter papers emphasised that there is a continued need for detailed surveys of Fijian mangroves in order to quantify natural variation among sites in terms of soil properties, vegetation, and levels of exploitation by local villagers, so that long-term patterns in the 'health' of mangroves can be established (Cameron et al., 2021a, Cameron et al., 2021b). Nevertheless, given the importance of mangrove systems to Fiji, several earlier reports have indicated that detailed taxonomic inventories of mangrove flora, and investigations into species dominance, are rare (Duke, Mackenzie and Wood, 2012; Waqa-Sakiti et al., 2013; Tuiwawa, Skelton and Tuiwawa, 2014; Cameron et al., 2021a).

In recent years, there has been an increase in socio-economic management of mangroves that incorporate both traditional and scientific knowledge, and recognizing the needs of local inhabitants in addition to implementing a biodiversity conservation agenda (Vierros et al., 2010; Pollard et al., 2015). These initiatives also provide a medium for documenting traditional knowledge and conservation methods, and promote local community, cultural and spiritual benefits (Thaman, 2002). In Fiji, native communities possess in-depth knowledge of coastal fisheries that provide baseline data for monitoring the effects of environmental degradation and efficacy of conservation initiatives (Thaman, Balawa and Fong, 2014).

The Rewa River mangroves form one of the largest intact and healthiest mangrove systems in Fiji. These forests are typified by native tree species such as *Rhizophora stylosa*, *R. samoensis*, and *Bruguiera gymnorhiza*, along with other mangrove-associated species such as *Heritiera littoralis*, *Lumnitzera littorea*, *Xylocarpus granatum* and *Excoecaria agallocha* (Tuiwawa, Skelton and Tuiwawa, 2014). However, there is some evidence that areas of the forest close to human habitation are becoming degraded and over exploited (MMC, 2013; Weber, 2021); and one study has suggested that plant diversity was in decline in some areas of Rewa Delta (Ellison and Fiu, 2010).

The aims of the study described in this paper were to perform an ethno-biological survey of an area of Rewa Delta mangroves near to the Nasilai River, in order to collect baseline data with respect to vegetation, soil properties, and current use of forest resources by local villagers. Transect surveys were used to assess for systematic variation in soil chemistry and flora with distance from the river to inland and shoreline to inland. Additionally, information was collected from local villagers to evaluate their awareness of the ecosystem services provided by mangroves, issues related to climate change, and sustainable management practices. Similar studies have been undertaken in various mangrove regions globally on biodiversity and ethnobotany, however, very few studies are carried out on the soil physio-chemical that determine the vegetation pattern from coast to inland. This study is an addition to the new understanding how mangrove response to physio-chemical parameters from coast to inland.

Materials and Methods

Study Sites

Field work was performed in November and December 2017 in mangrove forest near Nasilai village and along the Nasilai River, in Tailevu Province, Viti Levu, Fiji (Figure 1). This area of mangroves comprises approximately 28 km^2 of flat land, and generally lacks topographical features with high elevation, such as hills or slope. There are six villages situated within the locality of the Nasilai mangrove swamps: Nasilai, Vadrai, Muanaira, Kuiva, Naimalavu and Vaturua villages. Temperatures in this region range from 25-34^oC throughout the year, and the study area is categorized as a wet zone region of Fiji, receiving an average of 2-3 m rainfall per year.

Vegetation surveys and soil analysis

Five 100 m transects (Transects A-E), at least ~1-2 km apart, were established, starting from the coastline, and then moving inland along the Nasilai River (Table 1; Figure 1). Each of the ten 10 m sections of a transect were then used as the basis for a 10 x 10 m plot for vegetation surveying and soil sampling. Each transect therefore covered a total area of 1000 m^2.

One soil sample (~20cm^3) was taken at a depth of 5-10 cm in each sampling plot using a soil auger and stored in a zip lock bag. The samples were submitted to the Koronivia Research Station, Ministry of Agriculture, Fiji, for subsequent for nitrogen (N; ppt), Olsen phosphorous (P; ppm), salinity (%), moisture content (%) and pH analyses.

To survey mature vegetation, within each 10 m^2 plot, trees with a trunk greater than 5 cm in diameter were counted and identified to the species level with reference to Tuiwawa, Skelton and Tuiwawa, (2014) and Keppel and Ghazanfar (2011). Local plant names were corroborated by field assistants and village volunteers. Data on trunk diameter and canopy height of each mature tree are summarized in Supplementary Data S1.

To evaluate potential regeneration by saplings, within each 10 m^2 plot, a 1 m x 1 m quadrant was randomly placed, and the number of saplings with a trunk less than 5 cm in diameter were recorded. Where possible, saplings were identified to species level, but because young *Rhizophora* are difficult to separate they were pooled as *Rhizophora* spp.

Use of mangrove forest by local villagers

A questionnaire was used to gather information about mangrove use by members of two local villages, Vadrai and Nasilai. In each village, the village headman (Turaga-ni-koro) nominated 50% of households for an oral interview about how the mangroves impacted on their livelihood. Vadrai village consists of 16 households, and therefore produced eight respondents; Nasilai village consists of 30 households which was reflected in the sample of 15 respondents. Thus, the survey was based on a total of 23 respondents spread over the two villages.

Human Ethics approval for the survey was obtained from USP, and, additionally, permission was granted by the Ministry of iTaukei Affairs through the Tailevu District Council to visit both villages. Prior to entering the villages for data collection, a Fijian sevusevu ceremony was conducted using appropriate Fijian etiquette, including offering a gift of yaqona root (kava). Permission for the study was also granted by the village headmen and a Free Prior Informed Consent (FPIC) form signed by the headmen and village members.

The interview involved a formal questionnaire and a more informal discussion session (talanoa) where participants were able to elaborate further on their relationships with the mangrove system. The questions were translated into the native language for participants who were not fully able to understand English, and often paraphrased in order to obtain a more straightforward answer. The questionnaire covered four major topics: (1) awareness of mangrove ecology and environmental management; (2) mangrove-based income generation; (3) cultural significance of mangroves; and (4) the perception of climate change and its impacts on the mangrove system (see Supplementary Document D1).

Statistical analysis

All statistical analyses were performed using Genstat software (v21, VSN International, UK). Variation in soil and vegetation measurements among transects and along the transects were assessed by using generalized linear models. In these models count data, such as tree density and species richness, were assumed to have a Poisson error distribution, whereas continuous measurements, such as soil pH and chemical properties, were assumed to have a normal error structure. Transect was treated as a categorical explanatory factor with five levels (A-E), whereas distance along the transects was treated as a numerical explanatory variable. Pairwise comparisons of the five transects were made using least significance differences at $P < 0.05$.

Results

Soil properties

The physico-chemical properties of the soil samples were highly variable. Soil moisture ranged from 21-74% and the pH values were generally acidic and ranged from 3.5-7.2. Salinity ranged from 0.01-2.99 (%), suggesting that some samples were essentially salt free, whereas others had salinity levels close to that of sea water. In terms of nutrients, N concentrations of individual samples ranged from 0.04-0.16 ppt, and P concentration from 5-11 ppm.

Except for P concentration, the other four soil properties all differed significantly among the five transects ($P < 0.001$; Tables 1 & 2), with Transect A having, on average, soil with lower moisture levels, lower salinity, and lower N concentration than the other transects. In terms of pH, on average all the mangrove soils could be considered acidic; Transect B had the most acidic soil, with an average pH of 4.74, and Transect C the highest average pH at 6.61 (Table 1). Soil N and P concentration were not related to distance from the main river shore (Table 2). However, soil moisture content and salinity were negatively related to distance from the river, whereas soil pH showed an increased with distance (Figure 2; Table 2).

Vegetation survey

In the whole botanical survey (5000 m^2), 291 mature trees were recorded, with *B. gymnorhiza* being the dominant species, representing 72% of the mature tree specimens (Table 3). *Bruguiera gymnorhiza* was also the only species with mature specimens present in all five transects. The next most abundant species were *Cocos nucifera* (9% of mature specimens) and *Rhizophora* spp. (6% of mature specimens). In terms of juvenile plants, 1409 saplings were recorded in total survey area of 50 m^2. *Rhizophora* spp. accounted for just over half (57%) of the saplings recorded, followed by *B. gymnorhiza* (28%), *Cocos nucifera* (5%) and the fern *Acrostichum auruem* (2%; Table 3).

When considering the dominant mangrove tree species, there were significant differences among the five transects in terms of the abundance of both mature specimens and saplings of *B. gymnorhiza* and *Rhizophora* spp. (Tables 2 & 3). Mature *B. gymnorhiza* were similarly abundant in Transects B-E, but much lower in Transect A; whereas mature *Rhizophora* spp. showed the opposite pattern, and were most abundant in Transect A but relatively rare in the other four transects (Tables 3). In terms of saplings, both species were least abundant in Transect A, and more abundant in Transects C-E. The density of mature *B. gymnorhiza* trees exhibited a significant negative relationship with distance along the transect, whereas *B. gymnorhiza* saplings showed no overall trend (Table 2; Figure 3a, c). Densities of mature *Rhizophora* and saplings both exhibited negative relationships with distance from the main water course (Table 2; Figure 3b, d).

In terms of species richness, although 13 species of mature trees were recorded in total, the majority of these species only occurred in Transects A & B. Transects C & D only contained mature *Bruguiera gymnorhiza,* and Transect E contained only mature specimens of *B. gymnorhiza* and *Rhizophora* (Table 3). Transects A and B both contained 10 species of mature trees, many of which are considered valuable sources of fruits and nuts, such as *Cocos nucifera, Mangifera indica, Carica papaya* and *Citrus limon.*

The patterns in sapling species richness among the five transects were similar to that observed for the mature trees. Transects C, D and E only contained saplings of *B. gymnorhiza* and *Rhizophora,* whereas Transect B contained 8 species of saplings, and Transect A, the site nearest to Nasilai village, contained 23 species of saplings. Even given that three of the transects only contained one or two species of mature trees and saplings, the data obtained from Transects A and B meant that it was still possible to identify positive relationships between tree species richness for both mature trees and saplings with distance from the river inlet (Table 2; Figure 4).

Social survey

The participants in the survey consisted of approximately equal numbers of males (48%) and females (52%) with a wide age range (21 to 67 years). Most participants (83%) had completed secondary or tertiary education (Appendix 1).

The main benefits the villagers received from the mangrove forests were collection of firewood for domestic use, materials for house building and fenceposts, and collecting materials for uses such as in traditional medicines and making dyes (Table 4; Supplementary Document D1). Although Nasilai village is situated within the mangrove zone, Vadrai village is a short distance (~200m) away, and the villagers of Vadrai appear not rely on the mangrove to the same extent: only one (12.5%) household utilise mangroves for house posts, fencing, dye and gardening. Additionally, the villagers from Vadrai require permission to harvest mangroves from Nasilai village leaders who are the owners of the mangrove resource. Although 93% of respondents from Nasilai indicated that they harvested products from the mangroves weekly, this was only 12.5% in Vadrai, who predominantly (87.5%) said they would harvest mangrove products on a monthly basis (Table 4).

Apart from harvesting the mangrove trees themselves, villagers also pick or collect non-timber forest products from the mixed mangrove-associated vegetation, such as *Inocarpus fagifer* (“ivi”), coconuts, *Barringtonia edulis* (“vutu”) and *Pometia pinnata* (“dawa”), during their respective fruiting seasons. These products can be sold in markets for additional income. Pandanus leaves are processed and woven into mats and fans for cultural purposes (such as weddings and funerals) and also generate additional income.

In terms of marine products harvested from the mangroves, all households in Nasilai but one in Vadrai, indicated that they collected marine species such as fish and crabs and harvesting was mainly performed on a weekly basis (Table 4). The Vadrai household and around half of the Nasilai households stated that they sell these marine products to supplement their income.

Regarding sustainable management and exploitation of the mangroves, all respondents from both villages said they considered sustainable approaches when cutting down trees, despite no formal management plans being implemented (Table 5). All respondents were aware of the benefits they derived from the mangroves, and the importance of maintaining mangrove health. However, 100% of respondents from Nasilai indicated they use the mangrove for dumping domestic waste (Table 5).

All respondents from Nasilai and Vadrai were aware of climate change, mainly from local media, and all but one respondent was conscious of climate change threats and potential environmental impacts on their local mangroves (Table 5). Concerns about damage to the mangroves and coastal erosion appeared to be more strongly felt by Nasilai villagers than by those from Vadrai, possibly because Vadrai is farther inland than Nasilai (Table 5). The main climate change impact observed by respondents was rising sea level, which has caused sediment erosion and created water channels within the mangrove forest. One respondent from Nasilai stated that:

"Our village boundary is often flooded with seawater to ankle height during king tides."

Some elderly respondents claimed that:

"*We feel the sea level rising, we never experience this before like 30-40 years back everything was fine that time"*.

Of interest was that all Nasilai villagers had been exposed to climate change awareness education programs, whereas this had not taken place in Vadrai (Table 5). The Ministry of Forestry under the International Tropical Timber Organization (ITTO) project funded by Japan conducted awareness campaigns on climate change in Nasilai village and other Rewa Delta villages between 2017-2020. The objective of the project was sustainable management and community-based restoration of the vulnerable forest of the Rewa Delta. In this project, Nasilai was gifted native seedlings to plant near the shoreline to retain soil and protect the coastline. A committee nursery was also constructed to propagate native trees for future planting and rehabilitation. Awareness on importance of values derived from wetlands and training on planting techniques were undertaken. These were part of the national climate change mitigation and adaptation strategy.

Within the village, adaptive mechanism such as monthly meeting is organized when an urgent social or environmental issue arises, as Nasilai is vulnerable to shoreline dynamics and weather events. Concern are raised and discussed to revolve addressed issues internally. If issues are not resolved at the village council level, then is furthered to the chief higher and provincial council to make decisions.

Discussion and Conclusion

Apart from P concentration, all soil variables varied significantly among transects, and salinity, soil moisture and pH also varied systematically along transects. Average soil salinity was fairly low, below 3% per transect, possibly due to the flushing of soil by fresh water from the Nasilai river system. *Bruguiera gymnorrhiza* is often associated with areas influenced by freshwater, as it has relatively low salinity tolerance compared to other mangrove species, so its dominance of this system seems appropriate (Bunt, Williams and Duke, 1982; Alongi, 2015; Cameron et al., 2021a). Several authors have noted that mangrove forest soils can have variable pH levels even within a limited area (e.g., Wakushima, Kuraishi and Sakurai, 1994; Ball, 1988; Salmo, Lovelock and Duke, 2013), and the current study recorded soil pH values typical of acidic soils with pH of 3.5 - 5 near the shore, and more neutral values inland where soil pH ranged between 5.5 and 7.0. Soil moisture was very high (50-70%) in sampling zones near to the river shore but died out somewhat towards the inland ends of transects (20-30%).

Limitations of soil nutrient, such as N and P, constrain mangrove growth, and determine mangrove productivity and zonation patterns (Vilarrubia, 2000; Sherman, Fahey and Martinez, 2003; Reef, Feller and Lovelock, 2010; Sofawi, Nazri and Rozainah, 2017). The N and P concentrations obtained in the current study were sufficient to support mangrove species over the whole study area: average N per transect ranged from 0.7-1.2 ppt and P ranged from 7.4 to 9.4 ppm. Cameron et al. (2021a) have reported N concentrations for Rewa mangroves of similar magnitude between 1.0 and 1.8 ppt. A studies in Peninsular Malaysia showed similar range N (~ 0.4-1.2ppt) and P (~ 22-43ppm) (Sofawi, Nazri and Rozainah, 2017). Peninsular Malaysia and Fiji shares analogous tropical equatorial climate, and its parameters such as temperature and rainfall. Malaysia has similar mangrove species to Fiji but records some of the highest species diversity in mangrove forests globally.

Mangroves in Fiji can show distinct zonation patterns in terms of distance from the coast, with the seaward edge dominated by *Rhizophora* spp, and more mixed forests with *B. gymnorhiza* and other species such as *Lumnitzera littorea*, *Excoecaria agallocha*, and *Xylocarpus granatum* found further inland (Mueller-Dombois and Fosberg, 1998). Our results generally followed this pattern, in that mature *Rhizophora* were more abundant in Transect A which was closest to the seaward edge, and mature *B. gymnorhiza* were least abundant in Transect A and reached much higher densities in the remaining four transects. In general, the transects positioned further inland, away from coastal villages (Transects C-E), were highly dominated by *Bruguiera gymnorhiza* and species of *Rhizophora*, which is typical of mangroves in this region. However, the situation was not straightforward because the average density of both *Rhizophora* and *B. gymnorhiza* decreased along the transects away from the Nasilai river edge. These patterns were even further complicated because, although these zonation patterns were statistically significant when considering the data from the whole survey, they were not apparent for every transect.

The socio-economic survey indicated that villagers in this area received typical benefits from the mangroves. Villagers were generally aware of sustainable practices, but it was evident that mangroves near the village were degraded with visible signs of logging, bark removal, sapling damage, discarded domestic waste and domestic animals graze freely. Overall, it appeared that deterioration of the mangrove forests caused by human activities was more obvious than damage caused by the impacts of climate change. This has been a similar trend in most developing counties globally especially where communities living near mangrove ecosystem. A possible solution for this problem is to embed and strengthen ambitious objective on mangrove conservation at community level such as *"tabu"* which is practice parts of Bua province in Fiji (Pearson, Mcnamara, and Nunn 2019). Also setting up mangrove conversation areas and execute community working groups to monitor the environment and address issues accordingly during village council meetings. Woman and youths to be integrated into the decision-making process with regards to mangrove management so that new adaptations and mitigations plans will be added to the current climate crisis. Some studies indicate that community level management are a success in a few Asian countries (Datta, Chattopadhyay and Guha 2012).

In terms of the integrity of the mangrove community structure, another detrimental effect of human activities was that related to abnormally high species diversity in the vicinity of the villages. The vegetation survey identified 28 species of tree and mangrove-associated plant species over all five transects, although most of these plant species only occurred in the two transects (Transects A and B) that were closest to human habitation. In Transects A, the highest average species richness of mature trees and saplings occurred away from the river, and near to the villages of Nasilai and Vadrai. In this case, it seems likely that there is a direct causal relationship between exploitation of the mangroves by local villages and the substantial increase in plant species diversity. Clearance of deadwood by villages, and direct removal of canopy trees, would promote the survival of seedlings and saplings to reach maturity. The high density of fruit trees (e.g., papaya, lemon, mango, guava, and soursop) that would not normally be considered typical of intact mangrove forest suggests the presence of these trees is being fostered by local villagers.

The high diversity of fruit trees and other saplings near to the villages may not necessarily be due to direct planting of trees, and active farming, but it can be envisaged that any adventive seedlings might be protected by villagers if those species provide an additional resource. Similarly, the dumping of domestic waste in the forest would likely result in the deposition of fruit tree seeds, which, again once germinated, might warrant some protection. The resulting forest structure leads to some conflict if describing the mangroves as degraded in terms of their highly atypical vegetation, but of high value in terms of increased species richness and enhanced ecosystem services offered to local inhabitants. Cameron et al. (2021b) also highlighted the effects of selective harvesting in Rewa mangroves in terms of altering forest structure, opening the canopy, and causing a profusion of saplings. Because of low harvesting pressure, any negative effects of this harvesting may not be readily apparent and changes in forest structure only recognized over longer periods. These aspects of local, low intensity selective harvesting on vegetation structure, and whether villagers actively encourage the presence of commodity tree species, should be included in future socio-ecological investigations of Fijian mangrove management.

Comparison of vegetation data collected in this investigation with that obtained during the MESCAL study for the Nasilai mangroves (MESCAL report) suggested there had been little change in vegetation structure in the intervening five years between the survey, in that the main body of the forest away from villages remained fairly intact, and was still dominated by *B. gymnorhiza* and *Rhizophora*, with good numbers of saplings of these species throughout the forest. Unfortunately, the MESCAL study did not report data on seedlings and saplings, so we cannot gauge whether any changes in vegetation age structures or species recruitment have occurred. Additionally, no assessment of soil physico-chemical properties was performed to compare with the current study. As no permanent plots were established during the MESCAL study, it would appear advantageous for any future monitoring initiatives to focus on the locations of our sampling sites as specified using the GPS coordinates provided, and which would allow more direct comparisons of mature trees, saplings, and soil properties.

Regarding recommendations for future integrated ethno-biological surveys of Fijian, and other, mangroves, the results of this study support those of Cameron et al. (2021a), who highlighted the high levels of variation that can occur in terms of mangrove flora and soil properties over relatively small areas. In our study, the data for one site, Transect A, that was used extensively by local villagers was atypical in terms of tree species richness, botanical structure, and soil properties such as relatively low salinity, moisture, and N concentration. We found that soil properties, density of mature trees and saplings, and tree species richness differed along relatively short (100 m) gradients, and among the five transects. This spatial variability suggests that, when resources are limiting (limited data collection restricted to plot size due to time constrains), rather than use relatively low replications of highly detailed short transects, future vegetation and soil surveys may benefit from using higher replications of more isolated sites, and that investigations of trends related to distance from the coast might involve 100 m steps, rather than 10 m. Surveys should also specifically target sites close to, or including, human habitation for comparison with unexploited forest nearby to gauge levels of degradation caused by low intensity exploitation. To assess whether the manner and intensity in which local inhabitants use the mangroves, and ascertain their awareness of climate change and adoption of sustainable forest management practices, it would be valuable if future studies adopted a standardized questionnaire, possibly based on the format used in this study, so that answers could be directly compared among studies and over time.

In light of several recent reports of potentially dramatic global biodiversity declines (Montgomery et al., 2020; Hodge, 2020) there is a growing awareness of the need for long term ecological monitoring, which, if feasible, should be integrated with local and traditional knowledge and socioeconomic considerations (Calvache et al., 2021; Early-Capistrán et al., 2021; Rai et al., 2021). Long-term monitoring requires the adoption of standardized procedures that can provide meaningful quantitative data for comparisons with established reference baselines, such as those provided in this study and recent reports by Cameron et al. (2021a, b). The findings of this investigation highlight that sustainable management of Fijian mangroves requires interdisciplinary approaches that blend ecological, economic, and sociological data to ensure conservation of species, and preservation of forest integrity, whilst ensuring the future provision and accessibility of resources for local inhabitants.

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Dr Simon Hodge is currently an Assistant Professor at the University College Dublin, School of Agriculture and Food Science. More recently he worked at Lincoln University in New Zealand. His research focus on a wide range of topics, from sustainable and organic agriculture, to investigating the ecology of coastal insect communities.

Figure 1. Maps indicating location of study sites on island of Viti Levu, Fiji, and position of Nasilai and Vadrai Villages (Google Maps)

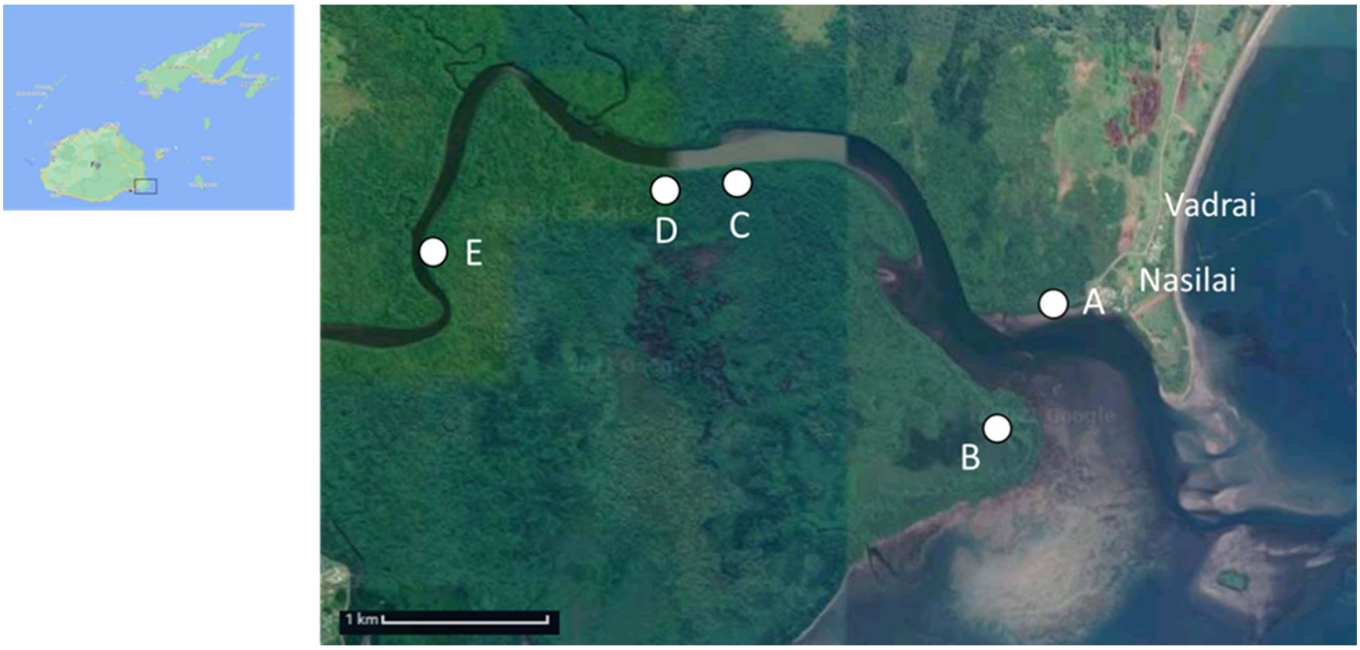

Figure 2. The relationships between moisture, pH and salinity (mean ± se; n = 10) of Nasilai mangrove soils with increasing distance from the bank of the major river inlet

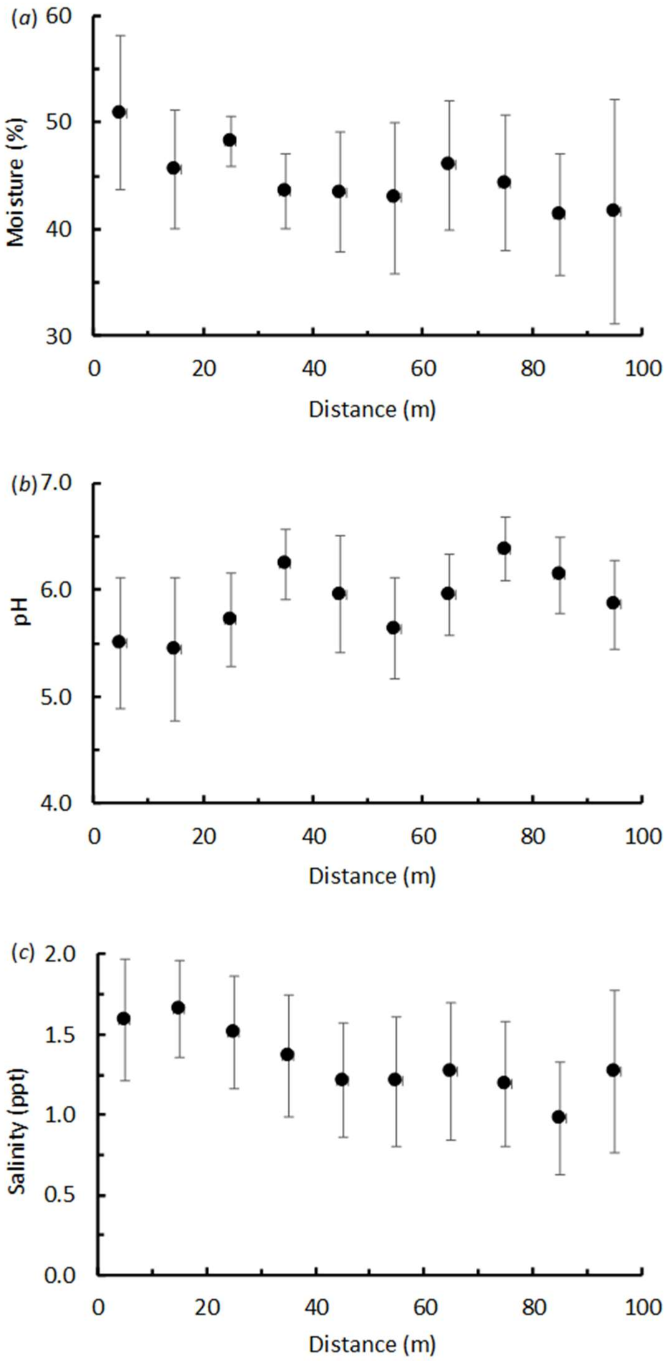

Figure 3. The number of *Bruguiera gymnorhiza* and *Rhizophora* spp. with increasing distance from the shore in five 100m transects (A-E) in mangroves at Nasilai, Fiji: (a, b) mature trees per 100 m^2 plot and (c, d) number of saplings per 1 m^2 plot

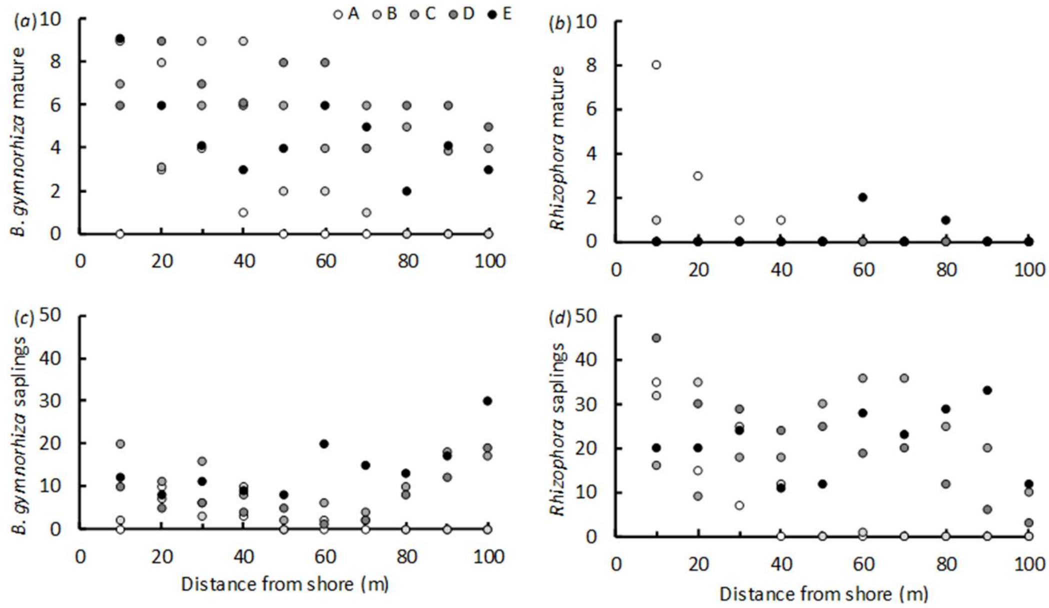

Figure 4. The number of species (a) of mature trees per 100 m^2 plot and (b) of saplings per 1 m^2 plot in mangroves at Nasilai, Fiji, with increasing distance from the shore in five 100m transects A-E (see Fig 1 for locations).

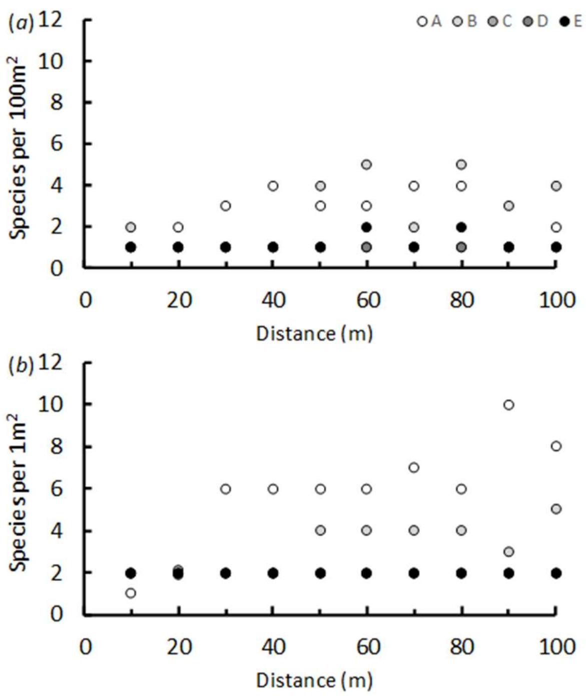

Table 1. Locations of the five 100 m transects (A-E) in the Nasilai mangroves, along with summary information on soil properties (mean ± se; n = 10). Letters not sharing a code are separated using the LSD at P < 0.05

Trans.	Coordinates (º)	Dist. from coast (km)	pH	Moisture (%)	Salinity (%)	Nitrogen (ppt)	Phosphorus (ppm)
A	-18.08382, 178.65136	1.00	5.95 ± 0.43[bc]	26.6 ± 1.8[a]	0.20 ± 0.10[a]	0.70 ± 0.13[a]	7.8 ± 0.6
B	-18.08891, 178.64704	1.17	4.74 ± 0.22[a]	42.2 ± 2.2[b]	1.17 ± 0.19[b]	1.21 ± 0.08[c]	8.8 ± 0.6
C	-18.07647, 178.63223	3.12	6.61 ± 0.04[c]	53.5 ± 2.8[c]	2.31 ± 0.10[d]	1.18 ± 0.08[bc]	8.7 ± 0.6
D	-18.07638, 178.62858	3.48	5.76 ± 0.25[b]	45.1 ± 3.8[b]	1.78 ± 0.15[c]	0.82 ± 0.17[ab]	8.1 ± 0.6
E	-18.08073, 178.61504	4.64	6.36 ± 0.05[bc]	56.6 ± 1.3[c]	1.18 ± 0.05[b]	1.15 ± 0.14[bc]	9.4 ± 0.3
LSD			0.71	7.26	0.36	0.04	1.55
P			< 0.001	< 0.001	< 0.001	< 0.001	0.200

Table 2. Summary of results of generalized linear modelling analyses to assess the effects of transect and distance from the main water course on various mangrove response variables. The error structure was designated as Poisson for count data, and normal for continuous measurements. The dispersion factor was estimated by the analysis algorithm and accounts for overdispersion from the assumed error structure. Transect was treated as a fixed categorical factor (A-E) and distance as a numerical predictor ranging from 1 to 10 to indicate the position of the sampling plot along the transect. Values given are the variance ratio and p value.

	Response variable	Error structure	Dispersion factor	Transect (4 df)	Distance (1 df)	Transect x Distance (4 df)
Soil properties	pH	Normal	-	15.89 <0.001	4.89 0.033	9.80 <0.001
	Moisture (%)	Normal	-	28.68 <0.001	5.01 0.031	3.98 0.008
	Salinity (%)	Normal	-	65.27 <0.001	14.32 <0.001	5.12 0.002
	Nitrogen (ppt)	Normal	-	5.89 <0.001	1.96 0.169	8.10 <0.001
	Phosphorus (mg/kg	Normal	-	1.57 0.200	0.19 0.665	3.24 0.022
Botanical survey	Rhizophora Mature density	Poisson	0.264	29.95 <0.001	82.47 <0.001	14.43 <0.001
	Rhizophora sapling density	Poisson	2.77	14.43 <0.001	34.45 <0.001	25.96 <0.001
	B. gymnorhiza mature density	Poisson	0.837	16.29 <0.001	26.25 <0.001	7.80 <0.001
	B. gymnorhiza sapling density	Poisson	3.16	13.23 <0.001	0.71 0.404	4.34 0.005
	Species richness mature trees	Poisson	0.285	16.94 <0.001	5.84 0.020	1.69 0.172
	Species richness saplings	Poisson	0.159	50.26 <0.001	37.76 <0.001	6.72 <0.001

Table 3. Total numbers of mature trees (per 1000 m^2) and saplings (per 10 m^2) recorded in five 100 m long transects in mangrove forests, at Nasilai, Fiji, in 2017. Where given, letter codes indicate separation of transects based on LSDs at $P < 0.05$ from GLM analysis.

		Mature trees						**Saplings**					
Common name Fiji/English	**Species**	**Trans. A**	**Trans. B**	**Trans. C**	**Trans. D**	**Trans. E**	**Total**	**Trans. A**	**Trans. B**	**Trans. C**	**Trans. D**	**Trans. E**	**Total**
Dogo/ Black mangrove	*Bruguiera gymnorhiza*	8^{a}	41^{b}	51^{b}	63^{b}	46^{b}	209	19^{a}	43^{a}	$112^{b\,c}$	72^{b}	143^{c}	389
Tiri / Red mangrove	*Rhizophora spp*	13^{a}	1^{b}	0^{b}	0^{b}	3^{b}	17	57^{a}	110^{ab}	218^{b}	213^{b}	212^{b}	810
Borete/ Feather fern	*Acrostichum auruem*	-	-	-	-	-	-	18	11	-	-	-	29
Soursop	*Annona muricata*	-	-	-	-	-	-	1	-	-	-	-	1
Uto in bulumakau	*Annora glabra*	1	-	-	-	-	1	-	-	-	-	-	-
Uto	*Artocarpus altilis*	2	-	-	-	-	2	6	-	-	-	-	6
Futu / Box fruit	*Barringtonia asiatica*	-	5	-	-	-	5	7	1	-	-	-	8
Vutukana	*Barringtonia edulis*	-	-	-	-	-	-	2	-	-	-	-	2
Rattan/ Gasau / na-tui	*Calanmus sp*	-	-	-	-	-	-	1	-	-	-	-	1
Dilo	*Calopyllum sp*	-	-	-	-	-	-	5	-	-	-	-	5
Papaya	*Carica papaya*	-	-	-	-	-	-	1	-	-	-	-	1
Vasa	*Cerbera manghas*	-	-	-	-	-	-	2	-	-	-	-	2
Lemon	*Citrus limon*	-	-	-	-	-	-	3	-	-	-	-	3
Coconut	*Cocos nucifera*	10	16	-	-	-	26	43	23	-	-	-	66
Cibicibi	*Cynometra falcata*	-	-	-	-	-	-	1	-	-	-	-	1
Walai	*Entada phaseoloides*	-	-	-	-	-	-	1	-	-	-	-	1
Sinu Gaga	*Excoecaria agallocha*	2	4	-	-	-	6	-	-	-	-	-	0
Kedra viv na yalewa kalou	*Heritiera littoralis*	-	4	-	-	-	4	-	19	-	-	-	19
Vau	*Hibiscus tiliaceus*	2	2	-	-	-	4	9	-	-	-	-	9
Ivi	*Inocarpus fagifer*	5	1	-	-	-	6	12	-	-	-	-	12
Vesi	*Intsia bijuga*	5	2	-	-	-	7	5	5	-	-	-	10
Mango	*Mangifera indica*	3	-	-	-	-	3	-	-	-	-	-	-
Vesi Wai	*Milletia pinnata*	-	1	-	-	-	1	1	-	-	-	-	1
Kura	*Morinda citrifolia*	-	-	-	-	-	-	5	-	-	-	-	5
Voivoi	*Pandanus caricosus*	-	-	-	-	-	-	11	-	-	-	-	11
Screwpine	*Pandanus tectorius*	-	-	-	-	-	-	8	-	-	-	-	8
Guava	*Psidium sp*	-	-	-	-	-	-	5	-	-	-	-	5
Dabi	*Xylocarpus granatum*	-	-	-	-	-	-	-	4	-	-	-	4
	Total	51	77	51	63	49	291	218	216	330	285	355	1409
	Species	10	10	1	1	2	13	23	8	2	2	2	25

Table 4. Proportion (%) of participants from Nasilai (n = 15) and Vadrai (n = 8) villages that responded positively to questions based on the uses and harvesting of mangrove products.

Topic	Question	Nasilai	Vadrai
Uses	Which of the following uses do you obtain from material harvested from the mangroves?		
	Firewood	100	100
	Medicinal	67	75
	Dye	53	37.5
	House building	47	12.5
	Chattels	27	12.5
	Fence posts	7	25
	Gardening	7	12.5
	Markings	7	0
	Spiritual	0	0
Harvesting	Do you usually harvest mangrove within 1 km of the village?	100	100
	Do you harvest leaves?	20	0
	Do you harvest bark?	100	87.5
	Do you harvest root?	100	87.5
	Do you cut the mangroves weekly?	93	12.5
	Do you cut the mangroves fortnightly?	7	0
	Do you cut the mangroves monthly?	0	87.5
	Do adult males cut the mangrove trees?	100	75
	Do adult females cut the mangrove trees?	100	37.5
	Do children cut the mangrove trees?	0	0
Marine	Do you harvest marine species from the mangroves?	100	13
	Do you harvest fish from the mangroves?	100	13
	Do you harvest crabs from the mangroves?	100	13
	Do you harvest prawn/shrimps from the mangroves?	0	0
	Do you harvest mussels from the mangroves?	0	0
	Do you sell what you harvest from the mangroves?	47	13
	Do you harvest marine species from mangroves weekly?	93	13
	Do you harvest marine species from mangroves fortnightly?	7	0
	Do you harvest marine species from mangroves monthly?	0	0

Table 5. Proportion (%) of participants from Nasilai (n = 15) and Vadrai (n = 8) villages that responded positively to questions based on sustainable management of mangroves and threats related to climate change.

Topic	Question	Nasilai	Vadrai
Sustainability	Do you or people in your communities use mangroves as dumping sites?	100	0
	Do you consider sustainable approaches when cutting down mangrove forest?	100	100
	Has there been any management actions implemented in your community?	0	0
	Are you aware of the threats that the mangrove systems in your area are facing?	80	87.5
	Are you aware of the advantages/benefits of mangroves?	100	100
Climate change	Do you know what climate change is?	100	100
	Have you observed climate change effects in your community?	100	87.5
	Have the mangrove ecosystem been damaged by natural disasters?	80	50
	Has there been any coastal erosion?	100	50
	Have you experienced any change in flowering and fruiting seasons?	0	0
	Has there been any climate change awareness conducted in your community?	100	0

Appendix 1. Profile (%) of respondents from Nasilai (N = 15) and Vadrai (N = 8) villages who took part in an oral interview related to their use of mangrove forests.

		Nasilai	**Vadrai**	**Total**
Gender	Male	60	25	48
	Female	40	75	52
Education	Primary	13	12.5	13
	Secondary	67	50	61
	Tertiary	20	25	22
	No Education	0	12.5	4
Age	21-30	27	12.5	22
	31-40	40	25	35
	41-50	13	50	26
	51-60	20	0	13
	61-70	0	12.5	4