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# Use of total allowable catch to regulate a selective marine aquarium fishery

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ABSTRACT

The Papua New Guinea (PNG) marine aquarium fishery was partly managed by total allowable catch (TAC) limits, implemented since the fishery's inception in 2008. Species-specific TACs, based on stock assessments conducted prior to the commencement of fishing, were established for all fish and invertebrate species presumed to be fished by the fishery. By analysing the selectivity of the PNG fishery in 2012, a large portion (74.9%) of the managed fish diversity ($n$ = 267 species) was found to be "weakly" to "strongly" avoided relative to their availability. More than half (53.2%; $n$ = 142) of the fish species with TACs were never fished in 2012. Of those species with TACs that were actually fished, 76.8% ($n$ = 96) of fish and all invertebrate catches never exceeded 1% of their TACs. Catches of only seven fish species exceeded 10% of their TACs. Catch records also identified 124 fish species that were fished in the absence of species-specific TACs. Unbiased recursive partitioning was used to examine ecological attributes of these species to help identify flaws in the methods used for initial TAC assignment. Refining the role species-specific TACs play in the management of this fishery is necessary to optimise managerial resources. The lessons learned from this approach to marine aquarium fishery management are likely to be of interest and value to PNG, other developing island nations, and marine aquarium fisheries globally.

## 1. Introduction

Difficulties in managing marine aquarium fisheries arise from the diversity of species traded. Globally, marine aquarium fisheries encompass more than 2200 fish species and over 550 species of invertebrates [41,55]. More than 45 countries export anywhere from three to 1320 species [41]. The life-history, demographic, and population data required for traditional stock assessments are typically unavailable for traded species [16,19], and a lack of institutional capacity and enforcement are often cited as impediments to management [16,7]. The use of catch limits is a tenet of traditional fisheries management [23,38,5]; however, the feasibility of employing this technique for marine aquarium fisheries is questionable, given the aforementioned limitations [7].

Total allowable catch (TAC) is a catch limit for a fishery that applies for a defined period of time. TAC can be used as a management technique for limiting fishing of specific taxa within marine aquarium fisheries [7]. Depending on the information available for the taxa being assigned a TAC, the calculation of the TAC may involve population modelling or set as a percentage of the estimated standing stock of the taxa. Where no information is available on the stock status, TACs are often based on historic export quantities or set at what is presumed to be a precautionary level (e.g., [7]).

The use of TAC in marine aquarium fishery management is most commonly employed for limiting the aggregate catch of live coral, live rock, or fishes [7]. Use of species-specific TACs to manage catches of specific fishes is limited among marine aquarium fisheries [7]. A notable example includes Vanuatu implementing a TAC for the flame angelfish, *Centropyge loriculus* [25,54]. In this case, the TAC was based on the quantity of individuals caught, with implementation occurring after prior establishment of the marine aquarium fishery. Most other fisheries employing species-specific fishing limits do so indirectly by means of quotas on the quantity of individuals traded or exported (e.g., Kiribati and Maldives) [7,13,45]. However, quotas offer a lesser degree of management control than TACs, given the former does not account for the portion of catch lost along supply-chains before commercial trade, which can be substantial [31].

The Papua New Guinea (PNG) marine aquarium fishery is atypical in that a TAC structure of management was implemented from the fishery's inception in 2008 [10,46]. Species-specific TACs, based on

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stock assessments conducted prior to the commencement of fishing, were established for all fish and invertebrate species presumed to be fished within the fishery. However, the necessity of this resource-intense component of PNG's marine aquarium fishery management strategy has not been evaluated against actual performance of the fishery.

Marine aquarium fisheries are typified by the export of a few species that comprise the bulk of individuals traded [41,55]. The PNG marine aquarium fishery has been shown to behave similarly, with evidence that the majority of the catch [31] and exports destined for the U.S. [41] were characterised by a small portion of the available diversity. This suggests that the PNG fishery was selective of the species being fished and that only a limited number of species may merit continual monitoring through species-specific TACs.

The aim of this study is to evaluate the selective nature of the PNG marine aquarium fishery and examine the effectiveness of the TAC component of this fishery's management. Refinement of the existing TAC structure is then discussed in relation to optimising the allocation of managerial resources. This is done using an entire year of fishery catch and export records.

## 2. Methods

### 2.1. Study fishery

Papua New Guinea comprises the eastern part of the island of New Guinea and a number of smaller islands in the Indo-Western Pacific region. In 2007, the National Fisheries Authority (NFA) contracted a U.S.-based consulting firm, EcoEZ Inc., to provide an assessment of marine resources with value to the marine aquarium trade. This consultancy subsequently developed into a three-year project to develop a sustainable marine aquarium fishery. This was followed by investment from the private sector in 2011, with the NFA granting a one-year licence to EcoAquariums Papua New Guinea Ltd. (hereafter EcoAquariums). While fishing and export activities occurred under EcoEZ Inc. between 2008 and 2010, this was part of the government funded consultancy and did not take place under real market conditions [46]. On this basis, the effectiveness of the TAC system of management is assessed only in relation to the commercial activities of EcoAquariums between 2011 and 2012.

### 2.2. Data collection

Catch and export records for PNG's marine aquarium fishery were obtained from the NFA. As a condition of licensing, EcoAquariums provided the NFA with a copy of all catch records and export invoices. Catch records came from the EcoAquariums electronic tracking database where each specimen caught was assigned a unique identification number [46]. Catch and export records were taken at face value, as misinformation could not be corrected. However, corrections were made when species names were misspelled or the listed name was a junior synonym of a valid species. Validity of scientific names was confirmed using the World Register of Marine Species [60].

TACs were set for individual fish and invertebrate species within the marine aquarium fishery management area (FMA) at Fishermen Island (9°32′00″S, 147°3′38″E). This FMA defined the spatial unit around Fishermen Island in which EcoAquariums' marine aquarium fishing activities were permitted. The species-specific TACs were set by the NFA with guidance from EcoEZ Inc. in 2008, prior to the PNG marine aquarium fishery first becoming active [31,46]. The TACs for invertebrates were set at 10% of the estimated population size, while the TACs for fishes were calculated using the Marine Aquarium Trade Coral Reef Monitoring Protocol (MAQTRAC), developed by Reef Check, that is based on size class abundance data [35,10]. Population demographics were estimated using underwater visual surveys at 40 sites within the 26 $km^2$ FMA [10]. TACs were to be valid for 12 calendar months with re-assessment, by means of underwater visual surveys, advised to occur within six months after expiration of the previous TACs. Where species were fished in the absence of a TAC, a TAC was to be set at the next annual reassessment [10].

Catch and export records were supplemented with biological information extracted from FishBase [15] that may have influenced the assignment of a TAC to a given species. The fields collected from FishBase included minimum depth, maximum length, nocturnality, and IUCN Redlist status for each species. To determine whether a species was nocturnal, the available biological information on FishBase was examined. Both direct statements of "nocturnal" and descriptions indicative of nocturnal behaviour were accepted to designate a nocturnal species. Each fish species was also characterised as a known or unknown marine aquarium commodity. All species listed in the marine aquarium database aquariumtradedata.org [41] were species designated as known aquarium commodities.

### 2.3. Data analysis

Catch records indicated that 0.7% ($n = 111$) of the fishery's total catch was sourced outside the Fishermen Island FMA; this catch was omitted from all analyses concerning TAC and selectivity of the fishery. The proportion of each TAC that was fished was determined by the quantity of individuals reported to be caught as a proportion of the assigned TAC for each species. Only fishes were examined further, given the limited quantity and diversity of invertebrate catch. It was not possible to assess relationships between the proportion of a fish's TAC fished and potential predictor variables of interest (i.e., catch quantity, export quantity, and mean export price) using parametric models, given the preponderance of zeros and the extreme right skew in the distributions of all variables. Instead, a conditional inference tree was constructed, using unbiased recursive partitioning according to the ctree function in the R package *partykit* [20], to determine whether catch quantity, export quantity, and mean export price (2012 US$) significantly predicted the proportion of the TAC fished for each species. This analysis relies on a permutation-based significance test to select predictor variables, and does not make assumptions as to the distribution of either the predictor or the response variables. Only significant ($P \leq 0.05$, with Bonferroni's correction) splits were considered. Unbiased recursive partitioning was also utilised to assess whether minimum depth, maximum length, nocturnality, or aquarium commodity status could predict the assignment of a TAC to a species.

To determine if taxa were being selectively fished by the fishery, the electivity or selection index ($D$) of Jacobs [21] was utilised:

$$D_i = (r_i - p_i)/((r_i + p_i) - (2 \times r_i \times p_i)), \quad (1)$$

where $r_i$ is the proportion of the fishery's total catch accounted for by a given fish species $i$ and $p_i$ is the proportion of fishery availability (i.e., the TAC) attributed to the given fish species $i$. $D_i$ is therefore defined as the relative difference between catch and availability of a species, and it gives an indication of the relative selection pressure on each fish species that is independent of relative abundance. $D_i$ ranges from $-1$ to $+1$, with positive values indicating a species overrepresented in the catch composition relative to its TAC availability and negative values indicating a species underrepresented in the catch composition relative to its TAC availability. A more contextual interpretation of selectivity is presented in Table 1.

## 3. Results

### 3.1. Catch and export

Catch records indicated a total of 14,615 individual fishes and 93 invertebrates were fished within the PNG fishery for the licence period spanning November 2011 to November 2012 (hereafter 2012). Catch records were able to identify, by quantity, 99.1% of fishes and 88.2% of