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Cooperative monitoring program for a catch-and-release recreational fishery in the Alphonse Island group, Seychelles: From data deficiencies to the foundation for science and management.

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ABSTRACT

Recreational fishing is a growing sector of tourism, and in theory, can be done in a sustainable manner such as through catch-and-release where fish are released rather than harvested. In some cases, stakeholders have taken the initiative to develop conservation strategies and management guidelines, as well as establishing monitoring programs of the resources they use. In this work, we provide a case study of a cooperative monitoring program in the Alphonse Group, Republic of the Seychelles, Africa, between a fishing company (Alphonse Fishing Company) and a local non-governmental organization (Island Conservation Society). These efforts have resulted in a code of conduct for the catch-and-release of target species, as well as long-term spatially explicit monitoring of catches, including fish size and catch location for five popular species through catch logs. During three seasons, the five key fish species monitored were giant trevally (*Caranx ignobilis*, n = 684), moustache triggerfish (*Balistoides viridescens*, n = 141), Indo-Pacific permit (*Trachinotus blochii*, n = 99), milkfish (*Chanos chanos*, n = 55), and yellowmargin triggerfish (*Pseudobalistes flavimarginatus*, n = 46). We found monthly catch variability across all species and that catches across seasons increased for *C. ignobilis (203.8%)*, *T. blochii* (45.5%), and *B. viridescens (25%)*, and decreased for *C. chanos (-65.6%)* and *P. flavimarginatus (-10%)*. Although there are considerations with implementing and maintaining such initiatives, we reviewed the benefits, including how these efforts can serve as the foundation for more thorough scientific research, co-production, and evidence-based management for the most sought-after species, *C. ignobilis*. We highlight how these cooperative initiatives may lead to formal co-management structures in recreational fishing, and also help to build capacity in government agencies for advancing economic prosperity while establishing sound long-term management and conservation strategies.

1. Introduction

Worldwide, it is estimated that recreational fisheries contribute approximately $190 billion US dollars annually to the global economy with between 220 million (World Bank 2012) and 700 million participants (Cooke and Cowx 2004). Within North America, Europe, and Oceania alone, an estimated 10.6% of the population partakes in recreational fisheries, accounting for an estimated 140 million persons (Arlinghaus and Cooke 2009; Arlinghaus et al., 2013). The rapid globalization of recreational fisheries to target novel gamefish (see Ditton et al., 2002; Freire et al., 2012; Barnett et al., 2016) has also resulted in an expansion of recreational fisheries to remote and largely environmentally intact areas, for example, the arapaima (*Arapaima* cf. *arapaima*) fishery in Guyana (Lennox et al., 2018), the golden dorado (*Salminus brasiliensis*) fishery in South America (Gagne et al., 2017; Chapman et al., 2018), mahseer (*Tor* spp.) in southeast Asia (Pinder

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et al., 2019), and the bonefish (*Albula* sp.) fishery worldwide (Wood et al., 2013; Adams and Cooke 2015). Many of these fisheries occur in remote locations and often in developing nations where they can provide economic benefits to local stakeholder groups and communities, including sustainable livelihoods for rural communities (Wood et al., 2013; Cooke et al., 2016). They may also provide economic incentives for conservation initiatives surrounding the fisheries and the habitats they depend on (Zwirn et al., 2005; Bower et al., 2014; Gupta et al., 2016). If tourism-driven recreational fisheries prove to be environmentally sustainable, it is believed both economic prosperity and simultaneous wildlife conservation may be realized within an ecotourism framework (Zwirn et al., 2005; Gallagher and Hammerschlag 2011; Fennell 2014; Griffin et al., 2017).

Catch-and-release (C&R) is often used as a means to help recreational angling work in harmony with the goals of economic growth without detrimental impacts to the target species (Cooke and Philipp 2004; Adams 2017). C&R involves releasing captured fish rather than harvesting them with the idea of reducing fishing mortality, thus has been proposed as a potentially effective management practice and conservation tool (Cooke and Schramm 2007). If science-based best practices for C&R are adopted by local stakeholders (Cooke et al., 2013; Chapman et al., 2018), a large proportion of fish caught by anglers will survive (see Brownscombe et al., 2017). The corollary is also true in that when best practices are ignored or not available, C&R may result in excessive physical injury and physiological stress, leading to post-release impairment and mortality (Muoneke and Childress 1994; Bartholomew and Bohnsack 2005; Cooke and Schramm 2007; Brownscombe et al., 2017). Considering that globally roughly 2/3rds of the estimated 47 billion fish caught by recreational anglers are released (Cooke and Cowx 2004), there may be detrimental impacts at the population level if lethal and sublethal effects of C&R are high (Post et al., 2002; Coleman et al., 2004; Allan et al., 2005; Coggins et al., 2007; Arlinghaus and Cooke 2009).

The impacts from recreational angling activities should be considered when developing guidelines and management plans since even low-intensity ecotourism focused on C&R may have negative effects on fish and their habitats (Gagne et al., 2017; Lennox et al., 2017b). For example, Lennox et al. (2017b) showed that, even with no air exposure, 33% of angled bonefish (*Albula glossodonta*) were depredated by blackfin reef sharks (*Carcharhinus melanopterus*) in the emerging recreational fishery in French Polynesia, and that any air exposure of the *A. glossodonta* after landing contributed to additional mortality rates (>60%) via post-release predation. For the *A.* cf. *arapaima* fishery in remote parts of French Guyana, Lennox et al. (2018) documented a 11% post-release mortality rate, likely attributed to exhaustion related to the fight and the inability of the fish to surface to respire after being released (*A.* cf. *arapaima* are obligate air-breathers). Beyond mortality related to C&R, the infrastructure and development associated with angling operations can lead to habitat modification, pollution, and a change in fish behavior (Lewin et al., 2006). Collectively, these issues may be especially detrimental in remote and fragile areas (Buckley 2000; Wong 2011), many of which are in the tropics and areas of high biodiversity (e.g., Cuba, Seychelles, French Polynesia) where remote tourism-based angling ventures are emerging.

An evidence-based approach is certainly needed if C&R recreational fisheries in remote locations are to lead to sustainable resource use, yet significant data deficiencies regarding basic species information, habitat use, and patterns of human use are quite common to emerging fisheries (Cooke and Suski 2005; Barnett et al., 2016). Further, in the regions where potential C&R fisheries may emerge, there may already be severe data limitations surrounding the existing fisheries (i.e., recreational, artisanal, subsistence, commercial) (Adams 2017). For example, Filous et al. (2019, 2021) reported the data-limited *A. glossodonta* artisanal fishery on Anaa Atoll, French Polynesia, had nearly collapsed and almost prevented the development of a viable C&R *A. glossodonta* fishery. Typically, data quantity often corresponds with the economic value of a given fishery, with commercial fisheries often having more information collected across long time series and for a suite of variables from multiple sources (Chen et al., 2003), when compared with recreational fisheries that are perceived as having a lower value. But even economically lucrative recreational fisheries often lack the monitoring data needed to accurately estimate the required parameters that are used to derive fishery stock assessments (Hilborn and Walters 1992; Walters 1998). For example, while the Florida Keys recreational bonefish (*Albula vulpes*), Atlantic permit (*Trachinotus falcatus*), and tarpon (*Megalops atlanticus*) fisheries are collectively worth $465 million (USD) per year (Fedler 2013), there has never been a formal stock assessment on any of the populations (Adams 2017; Adams et al., 2019). Furthermore, the lack of monitoring here is especially troublesome considering these fisheries (largely C&R based) and their habitats have likely experienced widespread declines (Larkin et al., 2010; Adams et al., 2014; Black et al., 2015; Brownscombe et al., 2019; Rehage et al., 2019). Indeed, a recent survey by Bower et al. (2020) revealed that capacity for recreational fisheries monitoring and management is lacking in many jurisdictions. While this information is needed to provide the foundation for more involved science and monitoring programs (Cooke and Cowx 2006; Coggins et al., 2007), in some cases, the recognition in the value of natural resources to localized economic prosperity has motivated stakeholders and rights holders to initiate or actively participate in their own monitoring and conservation strategies when other capacity (e.g., government support) is limited.

Prior to westernization, societies have long recognized the potential for marine resource overexploitation and had enacted intricate marine management systems (Johannes 1978; Friedlander et al., 2014; Friedlander 2018). In recent decades, these precautionary management practices have re-emerged and continue to be adopted (Johannes 2002; Filous et al., 2021), especially in communities where formal fisheries data is lacking (Johannes 1998). These successful community-based systems of management largely reflect self-monitoring strategies and can be found in many harvest oriented coastal fisheries (Ruddle and Johannes 1985; Ruddle 1994; Evans et al., 2000), however, such initiatives are seldom focused on C&R recreational fisheries. Granek et al. (2008) documents three successful recreational angler monitoring programs that led to improved management, including the rockfish fishery (British Colombia, Canada), the taimen fishery (Mongolia), and the salmonids fishery (Germany). Such monitoring programs included quantitative and qualitative data on caught fish and led to the formation of tools to evaluate stock trends, fishing effort, and spatial patterns of fishing effort to name a few. Although monitoring efforts may benefit socio-ecological coupled systems (Young and Horwich 2007; Granek et al., 2008; Kamikawa et al., 2015) it can also be limited by rigor, capacity, and synthesis of data collection. To overcome these challenges and to avoid low quantity and quality data, catch logs comprised of angler recorded catch data have become useful to understand and collect information on catch rates and other important biological related parameters (Anderson and Thompson 1991; Cooke et al., 2000; Boucek and Rehage 2015; Venturelli et al., 2017; Gibson et al., 2019). However, other hurdles for stakeholders and rights holders may emerge after data collection; related to analysis, interpretation, and management applications. Additional partnerships with research institutions may provide the necessary tools to bridge such gaps, eventually helping to balance economic prosperity and sustainable use by establishing evidence-based management and conservation strategies. To achieve truly sustainable recreational fisheries, and in the case of remote C&R tourism-based fishing operations, collaboration and co-management structures are needed among multiple partners, including the local communities, anglers and angling operators, conservation agencies, and eventually with policy makers (Adams 2017).

For this paper, we describe a tourism based C&R dataset recorded by the local fishing lodge (Alphonse Fishing Company) in cooperative efforts with a non-governmental organization (NGO) (Island Conservation Society) located around several remote island atolls in the Republic of Seychelles called the Alphonse Group. We provide the history of the fishery, along with the rationale as to why these stakeholder groups adopted a conservation and sustainable development ethos, as well as reveal some of the data that can be achieved and that acted as the foundation for in-depth research. Specifically, we highlight how catch data collected by this unique multi-partner collaboration can be extended to produce high resolution catch-data maps and how these catch logs provided a mechanism to implement, explore, and inform dynamic management strategies. In addition, we also present some of the considerations and potential resolutions for future and similar cooperative monitoring programs surrounding emerging C&R recreational fisheries.

2. Methods

2.1. Location

The Republic of Seychelles is an archipelagic country located in the Western Indian Ocean and comprised of 115 islands, distinguished as the Inner Islands which are largely granitic and the Outer Island Groups which are coralline. This region and its Economic Exclusion Zone span nearly 1.4 million km^2 and is largely supported by tourism (Archer and Fletcher 1996; Seetaram and Joubert 2018) with travel and tourism accounting for 40.5% of the country's gross domestic production in 2019 (World Travel and Tourism Council 2020). This case study focuses on the Alphonse Group in the Outer Islands, located 87 km south of the Amirantes Ridge (Fig. 1). The Alphonse Group consists of two low lying coralline atolls, separated by a 2.4 km wide channel 'Canal la Mort' and surrounded by deep oceanic waters (>2000 m deep) only 7–10 km away from the coral plateaus. Alphonse Atoll includes the land mass of Alphonse Island which covers an area of 174 ha and is the location of a small airport and tourism operation (see below for details), as well as a 540 ha lagoon and 402 ha of peripheral reef flats. St. François Atoll includes the small island of Bijoutier at nearly 2 ha and the 17 ha island of St. François, as well as a 1650 ha lagoon and 3, 732 ha of reef flats (Fig. 1). Both atolls consist of a shallow (<10 m) central lagoon surrounded by extensive shallow water reef flats of sand, coral rubble and seagrass (Spencer et al., 2009).

2.2. Tourism and stakeholder history on Alphonse Group

Beginning in the late 1800s, Alphonse Island was occupied and developed as a coconut plantation to produce copra, with other exports including turtle meat, turtle shell, pearl shell and salted fish (Sesel 2010). In 1999, the Alphonse Island Resort in cooperation with the Islands Development Company (IDC, https://www.idcseychelles.com), opened as a remote luxury tourism operation. After numerous attempts to operate a financially viable operation, the lease was sold to Alphonse Island Lodge (AIL, https://www.alphonse-island.com/en) in 2013 with two brands focused on nature orientated activities: Alphonse Fishing Company (AFC, https://www.alphonsefishingco.com) and Blue Safari Seychelles (BSS, https://www.bluesafari.com/en). While AFC is dedicated to fly fishing that occurs during the northwest monsoon season (primarily September–May), BSS is focused on ecotourism and includes diving, nature walks, snorkeling, sea excursions, surfing, etc. AIL currently caters up to around 100 occupants who participate in a variety of nature based activities on a daily basis via the two brands, AFC and BSS. The Alphonse Conservation Center, managed by NGO, Island Conservation Society (ICS, https://www.islandconservationseychelles.com) opened in 2007 and focuses on preserving and studying the ecosystem of the Alphonse Group. The Alphonse Foundation (AF) was set up to raise funds and lead the conservation efforts on these atolls. Beyond hotel occupants and on-island staff (AIL, AFC, BSS, IDC, ICS),

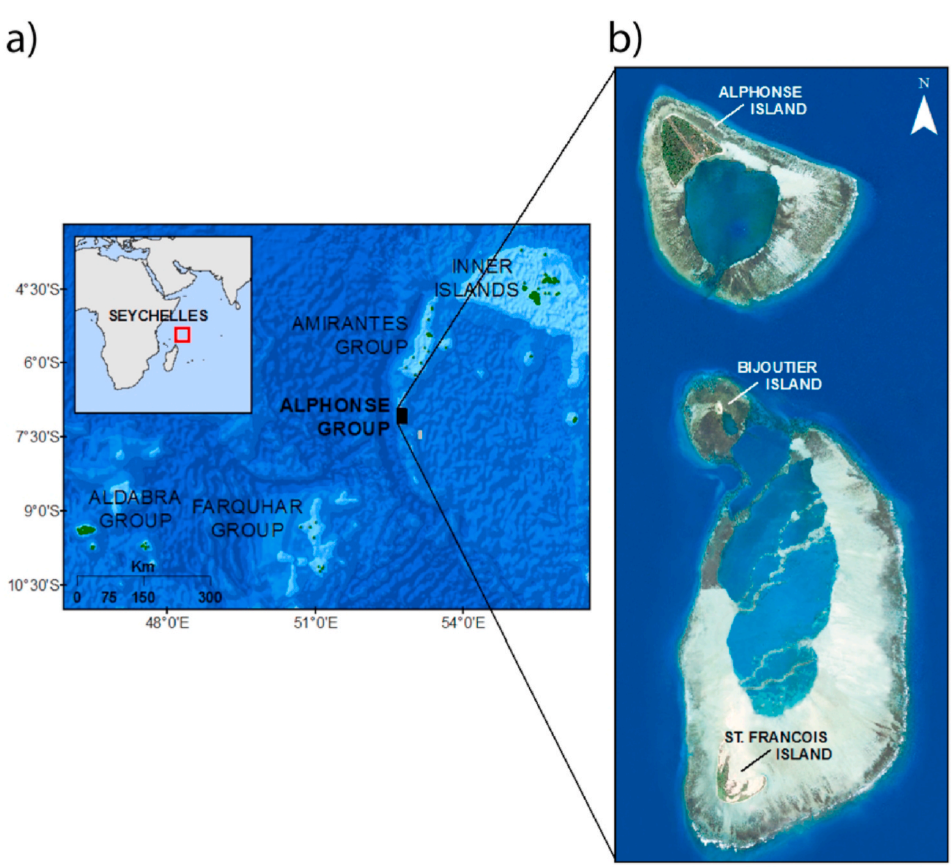

Fig. 1. a) Alphonse Group in the Outer Island Groups, Republic of Seychelles, including location of the Seychelles in the Indian Ocean and b) Alphonse Island, Bijoutier Island, and St. François Island.

there are currently no local communities inhabiting this remote island group.

AFC imposes strict C&R practices with its guests and has year-round access to the islands, shallow flats, and lagoons. However, limited and occasional commercial fishing vessels (primarily long-liners and sea cucumber harvesters) along with charter fishing yachts have been observed to harvest and/or partake in conventional angling along the reef edge (Devan Van Der Merwe personal communication). The main species targeted by the clients of the AFC are the giant trevally (*Caranx ignobilis*), bluefin trevally (*Caranx melampygus*), *A. glossodonta*, Indo-Pacific permit (*Trachinotus Blochii*), moustache triggerfish (*Balistoides viridescens*), yellowmargin triggerfish (*Pseudobalistes flavimarginatus*), and milkfish (*Chanos chanos*). Considering all targeted species are largely data deficient when it comes to C&R and broader management, AFC adopted a proactive precautionary management strategy involving the fishery. Since 2012, fly fishing activities with the AFC have been targeted bookings of a maximum of 12 anglers per week during the fishing season, with it currently being reduced to pre-sold 10 anglers per week and 2 rods reserved for on location sales that are utilized 50% of the time. A week fly fishing package consists of six guided fishing days per week on St. François, the main island where fish are targeted. Typically, two guests are paired each day with an AFC guide and fishing occurs from a 4.9 m flats skiff or by wading in the seagrass and reef flats.

2.3. Catch-and-release guidelines and monitoring initiative

Related to C&R, AFC developed a code of conduct for all guides and clients to adhere to when targeting gamefish. Upon arrival, all anglers are presented with the code of conduct, which includes C&R fly fishing only and minimizing handling time for fish that are landed. ICS, in extensive collaboration with AFC, later refined the code of conduct to include specific handling instructions based on evidence and anecdotal accounts from other fisheries and locations (see Supplement Fig. S1). Additional modifications included barbless hooks, stronger tackle to reduce fight times, rubberized mesh nets, how-to instructions for photographs, release and reviving fish strategies, and general environmental awareness practices for other species (i.e., corals, turtles, birds, predators) and their habitats. Although ICS had limited capacity and expertise related to recreational fisheries, their ability to coordinate data collection and recognition for the importance of baseline data collection led to a monitoring program in collaboration with AFC that focused on *C. ignobilis*, *C. chanos*, *T. blochii*, *B. viridescens*, and *P. flavimarginatus*. Even though *A. glossodonta* are one of the main target species of guests visiting Alphonse Group, with potential catch numbers exceeding >20 per angler per day, it was deemed too cumbersome to include monitoring of *A. glossodonta*. Though AFC had been recording catch numbers since 2012, the collaborative efforts between AFC and ICS to collect more detailed information began in 2017, which included spatially explicit data through the use of geographic positioning system (GPS) watches worn by the fishing guides. Guides were issued Garmin Quatix III GPS watches (Garmin United States) and recorded the capture location of fish, with this data managed using the Garmin BaseCamp software (https://www.garmin.com/en-US/software/basecamp/). From September 2017 to May 2019 (i.e. three complete fishing seasons) AFC and ICS recorded the total number of *C. ignobilis*, *C. chanos*, *T. blochii, B. viridescens,* and *P. flavimarginatus* caught by guests per day. While data were recorded on the raw count of fish caught, no angling effort was readily recorded, thus, not allowing for catch per unit calculations. AFC guides also recorded information about the fish (species, fork length), time of day, and, occasionally, other environmental conditions (cloud cover, wind direction, wind strength, wave action, tidal phase). Collected catch data were then used to produce generalized density maps by ICS to help examine potential high-pressure angling areas.

2.4. Catch-and-release analyses

2.4.1. Data filtering process

While GPS watches were provided to guides to record meta data for each target species, on occasion technical difficulties and logistical challenges required them to provide a general location rather than recording the exact latitude and longitude. Fortunately, because of the nature of the recreational fishery, a very detailed map of the fishing areas with 66 named flats and channels was created and could be used to provide coarse spatial data for capture location when a GPS watch was not used. In these cases, substituted locational data were re-reviewed by the fishing guides to ensure accuracy. Further, any *C. ignobilis* caught at the main dock of Alphonse Atoll were removed from all reporting and analyses since fish were 1) often captured in atypical fashion (i.e., bait), 2) used to evaluate C&R angling effects related to a separate study, and 3) are considered to be habitual to the location because it sometimes serves as a feeding station by guests.

2.4.2. Statistical analyses

All statistical analyses were conducted using R 3.6.2 (R Development Core Team 2019) and relevant code can be found at https://github.com/lucaspgriffin. Overall species catch counts and percent change were examined across fishing seasons (i.e., 2017–2018, 2018–2019, 2019–2020 fishing seasons). To examine size differences across species and fishing seasons, we used the one-way repeated measures analysis of variance (ANOVA) test or the non-parametric Kurskal-Wallis test when statistical assumptions (e.g., large outliers, homogeneity of variance, large deviations from normality) were violated. ANOVAs and Kruskal-Wallis tests and associated tests/estimations were implemented using the rstatix package (Kassambara 2019). In addition, to evaluate the relationship between month and catch counts for each species, we implemented generalized linear mixed models (GLMMs), using the glmmTMB package (Magnusson et al., 2017), with fishing season as the random effect term. Either the Poisson, negative binomial, or Quasi-Poisson distribution were used in the GLMMs depending on Akaike information criterion (AIC), using the MuMIn package (Bartón 2014), and if overdispersion was detected, using the performance package (Lüdecke et al., 2019). Interpretation, validation, and predictions of GLMMs were implemented using the sjPlot (Lüdecke 2018), sjstats (Lüdecke 2017), and performance (Lüdecke et al., 2019) packages. All plotting and graphics were generated in either the ggplot2 (Wickham 2011) or the tmap (Tennekes 2018) packages.

To examine species catch data across space, we constructed 99%, 95%, and 50% kernel density estimations (KDEs) and subsequently plotted the 95% and 50% KDEs on top of the Alphonse Group. First, catch point data for each species and fishing season, as well as all seasons combined, were used to fit kernel utilization distributions (KUDs, i.e., a bivariate probability density function of use) and then the estimated the 99%, 95%, and 50% KDEs from each KUD were extracted (Worton 1989; Lichti and Swihart 2011). Essentially, the KDE represents a vectorized polygon that resulted from isopleths around a given percentage (e.g., 99%, 95%, 50%, etc.) of the cumulative utilization distribution (i.e., KUD). Here, the 50% catch data KDE represents the core catch area for the given species. KUDs and subsequent KDEs, with a 150 m smoothing parameter, were derived and implemented using the adehabitatHR package (Calenge 2006). We decided to use a larger 150 m smoothing parameter to account for the uncertainty around some catch locations, i.e., when locational data was not recorded via GPS but derived from generalized fishing locations. The total area of the 99%, 95%, 50% KDEs for all species across fishing seasons were also calculated using the *kernel.area* function in the adehabitatHR package (Calenge 2006). Further, using the overall extracted 95% and 50% KDEs from each species, we also examined the percent area overlap from one species KDE to the other species' KDEs. Percent area overlap was measured as the proportion of species *i*'s KDE that is overlapped by species *j*'s KDE (Kernohan et al., 2001). All summary statistics below are reported as mean ± standard deviation unless specified otherwise.

3. Results

A total of 684 *C. ignobilis*, 55 *C. chanos*, 99 *T. blochii*, 141 *B. viridescens*, and 46 *P. flavimarginatus* were reported caught for the 2017–2018, 2018–2019, 2019–2020 fishing seasons, combined. While overall reported catch data across all seasons had increased for *C. ignobilis* (203.8%), *T. blochii* (45.5%), and *B. viridescens* (25%), they decreased for *C. chanos* (−65.6%) and *P. flavimarginatus* (−10%) (Table 1).

For those fish that had their fork lengths measured, body size ranged from 20–140 cm for *C. ignobilis* (n = 657, 75.5 ± 14.7 cm), 43–130 cm for *C. chanos* (n = 29, 96.1 ± 15.3 cm), 20–76 cm for *T. blochii* (n = 81, 50.1 ± 15.4 cm), 15–58 cm for *B. viridescens* (n = 109, 32.8 ± 9.2 cm), and 20–72 cm for *P. flavimarginatus* (n = 38, 39.9 ± 12.2 cm) (Fig. 2). There was no difference in body size among fishing seasons *for C. ignobilis* (H(2) = 0.45, p value = 0.8), *C. chanos* (H(2) = 2.72, p value = 0.26), and *B. viridescens* (F(2,35) = 2.12, p value = 0.14). However, there was for a decrease in body size for *T. blochii* (H(2) = 7.39, p value = 0.03) with a moderate effect size (0.69) between 2017–2018 (n = 27, 57.4 ± 9.66) and 2019–2020 (n = 37, 44.8 ± 17.6) and for *B. viridescens* (H(2) = 6.98, p = 0.03) with a small effect size (0.05) between 2017–2018 (n = 46, 34.6 ± 8.9 cm) and 2019–2020 (n = 47, 30 ± 9.43 cm) seasons.

All count models, including fishing season as a random effect term, indicated catch counts for a given species were variable across selected months to some degree (Table S1, Fig. 3). While variance was relatively high, due to sample size, the highest predicted catch counts ($\hat{y}$) occurred in February ($\hat{y}$ = 46, CI 22 to 96) and January ($\hat{y}$ = 33, CI 16 to 69) for *C. ignobilis*, December ($\hat{y}$ = 6, CI 3 to 11) and January ($\hat{y}$ = 5, CI 3 to 8) for *C. chanos*, October ($\hat{y}$ = 8, CI 5 to 13) for *T. blochii*, October ($\hat{y}$ = 10, CI 6 to 17) and November ($\hat{y}$ = 8, CI 5 to 14) for *B. viridescens*, and February ($\hat{y}$ = 3, CI 2 to 6) for *P. flavimarginatus* (Fig. 3).

3.1. Kernel density estimations

KDE catch areas were largest for *C. ignobilis* (25.3 ± 17 km^2), followed by *B. viridescens* (10.8 ± 6.55 km^2), *T. blochii* (6.44 ± 4.93 km^2), *P. flavimarginatus* (4.51 ± 2.81 km^2), and *C. chanos* (4.18 ± 4.24 km^2) (Fig. 4, Table S2).

Generally, KDE catch data plots indicated areas of highest catch density were fairly consistent across the three fishing seasons for all species (Fig. 5). However, for each species, some variability existed from season to season with concentrations varying in specific locations and in core catch areas (i.e., 50% KDE; Fig. 5, Table S2). Overall, *C. ignobilis* KDEs were concentrated around the outer atoll edge and along shallow water flats surrounded by deeper water within the lagoon, *C. chanos* KDEs were mostly concentrated around the outer atoll edge, *T. blochii* KDEs were concentrated within the interior shallower flats, and both triggerfish species followed similar patterns to *C. ignobilis* with concentrated catch areas on the outside edges and on flats crossing the lagoon within the atoll.

Overall, the proportion of catch area KDEs covered by other species' KDEs was on average 0.79 (±0.19) for 95% KDE catch areas (Table 2a) and 0.60 (±0.31) for 50% KDE core catch areas (Table 2b). The overlap of core catch areas across species was greatest for *C. ignobilis* (0.94 ± 0.05), followed by *C. chanos* (0.87 ± 0.14), *B. viridescens* (0.82 ± 0.17), *T. blochii* (0.68 ± 0.21), and *P. flavimarginatus* (0.63 ± 0.22; Fig. 5, Table 2b).

Table 1
Overall species catch counts and percent change across seasons. Overall percent change was calculated using the first and last fishing seasons (i.e., 2017–2018 and 2019–2020). Positive and negative reported values indicate an increase or decline in catch counts, respectively.

Species	Season	Number caught	Seasonal percent change	Overall percent change
C. ignobilis	2017–2018	104		
C. ignobilis	2018–2019	264	153.8	
C. ignobilis	2019–2020	316	19.7	203.8
C. chanos	2017–2018	32		
C. chanos	2018–2019	12	−62.5	
C. chanos	2019–2020	11	−8.3	−65.6
T. blochii	2017–2018	33		
T. blochii	2018–2019	18	−45.5	
T. blochii	2019–2020	48	166.7	45.5
B. viridescens	2017–2018	52		
B. viridescens	2018–2019	24	−53.8	
B. viridescens	2019–2020	65	170.8	25
P. flavimarginatus	2017–2018	20		
P. flavimarginatus	2018–2019	8	−60	
P. flavimarginatus	2019–2020	18	125	−10

4. Discussion

The cooperative monitoring of the five prominent target species in the recreational fishery of the Alphonse Group has already provided important data that can be used to guide management and continued monitoring efforts. Overall, these monitoring efforts indicated that *C. ignobilis* were caught the most, followed by *B. viridescens*, *T. blochii*, *C. chanos* and, lastly, *P. flavimarginatus*. Further, the predicted catch counts highlighted the monthly catch variability and provides reference points to gauge potential angler pressure allocation across species and time. Across the three seasons of catch data, there has been an increase in catch for *C. ignobilis*, *T. blochii*, and *B. viridescens* and a decrease in catch for *C. chanos* and *P. flavimarginatus*. Although the increases in catch could be a reflection of angler effort and demands, especially for *C. ignobilis*, this information may also reveal an increased sensitivity of some species to fishing pressure (Post et al., 2002). Indeed, some declines in catch rates in fisheries may be related to conditioned hook avoidance due to, not only effort, but individual, e.g., boldness tendencies, and species-specific behavioral characteristics, e.g., feeding strategies (Askey et al., 2006; Alós et al., 2015; Klefoth et al., 2017; Lennox et al., 2017a). It should be noted and cautioned that although the number of *C. ignobilis* caught increased substantially across seasons, fish populations have been documented to exhibit hyperstability, in which catch per unit effort remains stable or increases as true abundances decline (Hilborn and Walters 1992). Here, while the number of *C. ignobilis* caught have increased, it does not necessarily indicate the population is not vulnerable to the impacts of fishing pressure and handling practices. As guide and angler experience and/or effort increases, catch rates may as well, masking the actual trends in the population, thus, adopting monitoring of both catch data and effort is warranted. This issue of hyperstability may become particularly problematic within flats recreational fisheries where anglers target the specific habitats that the species select for (Dassow et al., 2020). If high fishing effort and fish abundance remains decoupled, the viability of the targeted fishing populations may be jeopardized (Camp et al., 2016).

Additional findings highlight while no difference in body size was detected across seasons for *C. ignobilis*, *C. chanos*, or *B. viridescens*, there was a decrease in body size for *T. blochii* and *B. viridescens* between the first and last seasons of monitoring. Although additional monitoring data is likely needed for confirmation, some Alphonse Group fisheries may be more robust to fishing pressure since anglers are capturing a similar sized and aged fish from season-to-season. The documented decrease in body size for *T. blochii* and *B. viridescens* may be more related to their ecology (e.g., small home ranges, territorial), but highlights the need for continued monitoring on Alphonse Group to determine if fishing induced behavior/size selection could occur. For example, considering larger individuals are typically targeted and more susceptible to angling (van Poorten and Post 2005; Jorgensen et al., 2007;

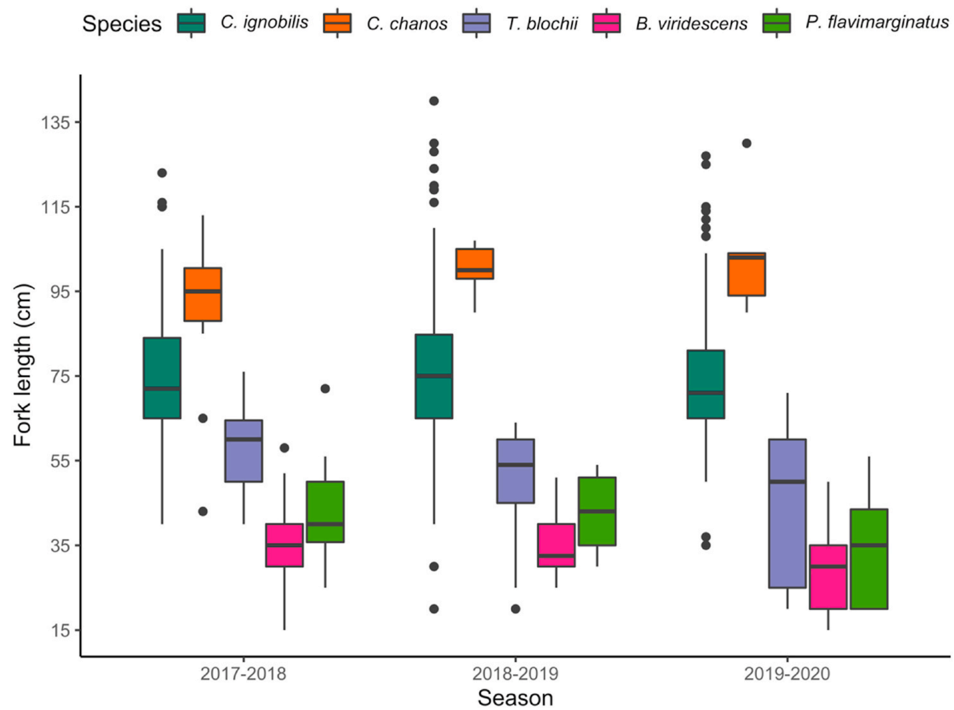

Fig. 2. Fork length (cm) of each species included in monitoring program by fishing season. Median indicated by the horizontal line and first and third quartiles (the 25th and 75th percentiles) indicated by whiskers within each boxplot.

Tsuboi and Endou 2008; Askey et al., 2013), any current or future observed declines in capture size could be attributed to induced 'timidity' of larger individuals (Arlinghaus et al., 2016, 2017).

Finally, critical to effective recreational fisheries conservation planning (Black et al., 2015), spatially explicit catch data and associated maps provided additional insights on angling pressure distribution. Each species was found to have specific core catch areas across the atolls that somewhat varied from season-to-season. Such catch data maps are useful to help guide potential management solutions that include temporarily closing areas from fishing activities. Further, catch area size was found to be species-specific with overlap disproportionally occurring across species, suggesting when targeting one species there may be a higher or lower likelihood to opportunistically target other fisheries.

4.1. Stakeholder collaboration for scientific research

Similar to this stakeholder driven initiative, other monitoring programs carried out by a consortium of stakeholders have been useful for management and generating scientific questions related to the health of animal populations and their ecosystems (Cohn 2008; Cerrano et al., 2017). For example, initiatives leading to scientific advancements in the marine realm include monitoring catch rates in recreational fisheries (see Granek et al., 2008), monitoring coral reefs and their assemblages (Hodgson 1999; Stuart-Smith et al., 2017; Vieira et al., 2020), the spread of marine invasive species (Delaney et al., 2008), and the benefits of marine protected areas (Strain et al., 2019). However, unique to this Alphonse Group stakeholder initiative and collaboration, the monitoring program on Alphonse Group has proved beneficial by generating additional questions that are in line with some of the most pressing questions in recreational angling (Holder et al., 2020b), such as, how to quantitatively test the impacts of fishing pressure on fish behavior? Or, how to promote sustainable practices in a privatized fishing industry? For example, data collected by AFC, in conjunction with ICS, indicate there are variable levels of overall and seasonal fishing pressure across the Alphonse Group. This, in combination with anecdotal observations from fishing guides about the increased weariness or 'timidity' (see Arlinghaus et al., 2017) of target species have led to questions about if fishing pressure is excessive and/or have altered the behavior of fish around the islands. In particular, *C. ignobilis* are often reported to be increasingly timid and more difficult to catch than in prior years, before intensive fishing pressure occurred. As *C. ignobilis* C&R fishing operations continue to expand to neighboring, lesser-pressured Outer Islands (e.g., Cosmoledo, Farquhar, Astove, Providence), initial exceptionally high catch rates may lead to severe declines in catchability, followed by a continued slow decline, as observed in other fisheries (van Poorten and Post 2005; Askey et al., 2006). Considering *C. ignobilis* is currently the main species of interest for visiting anglers to Alphonse Group, there are new questions emerging about best practices and angling capacity for the fishery as a whole (e.g., limits on angler numbers, closures and/or cycling fishing locations) and general concern about the sustainability of the fishery into the future. In fact, for all five species monitored within this fishery, there have been no studies that confirm their post-release survival and, ultimately, their suitability as C&R fisheries (Cooke and Suski 2005). Critical to this fishery and other *C. ignobilis* based recreational fisheries, this C&R evaluation on survival is needed and has been identified as a major knowledge gap surrounding this species (Grabowski and Franklin 2017). For *T. blochii*, Holder et al. (2020a) found that *T. falcatus*, a closely related species, in the Florida Keys were robust to angling effects (assuming predator presence is low). Lastly, the appropriateness of *C. chanos* and both triggerfish species as potential C&R candidates is still unknown. Collectively, these new realizations have spurred additional conversations among stakeholder groups to better understand the amount of fishing effort Alphonse Group can support while maintaining high catch rates of large fish and intact habitats (Adams 2017).

These sentiments in combination with the preliminary data collected via the monitoring program, history of conservation mindedness, and willingness of stakeholders to seek further quantitative evidence related to *C. ignobilis* angling pressure, has resulted in the formation of new partnerships with research scientists from several institutions. A deeper collaboration between AFC, ICS, and academic research partners formed to examine *C. ignobilis* C&R effects and how their spatial ecology

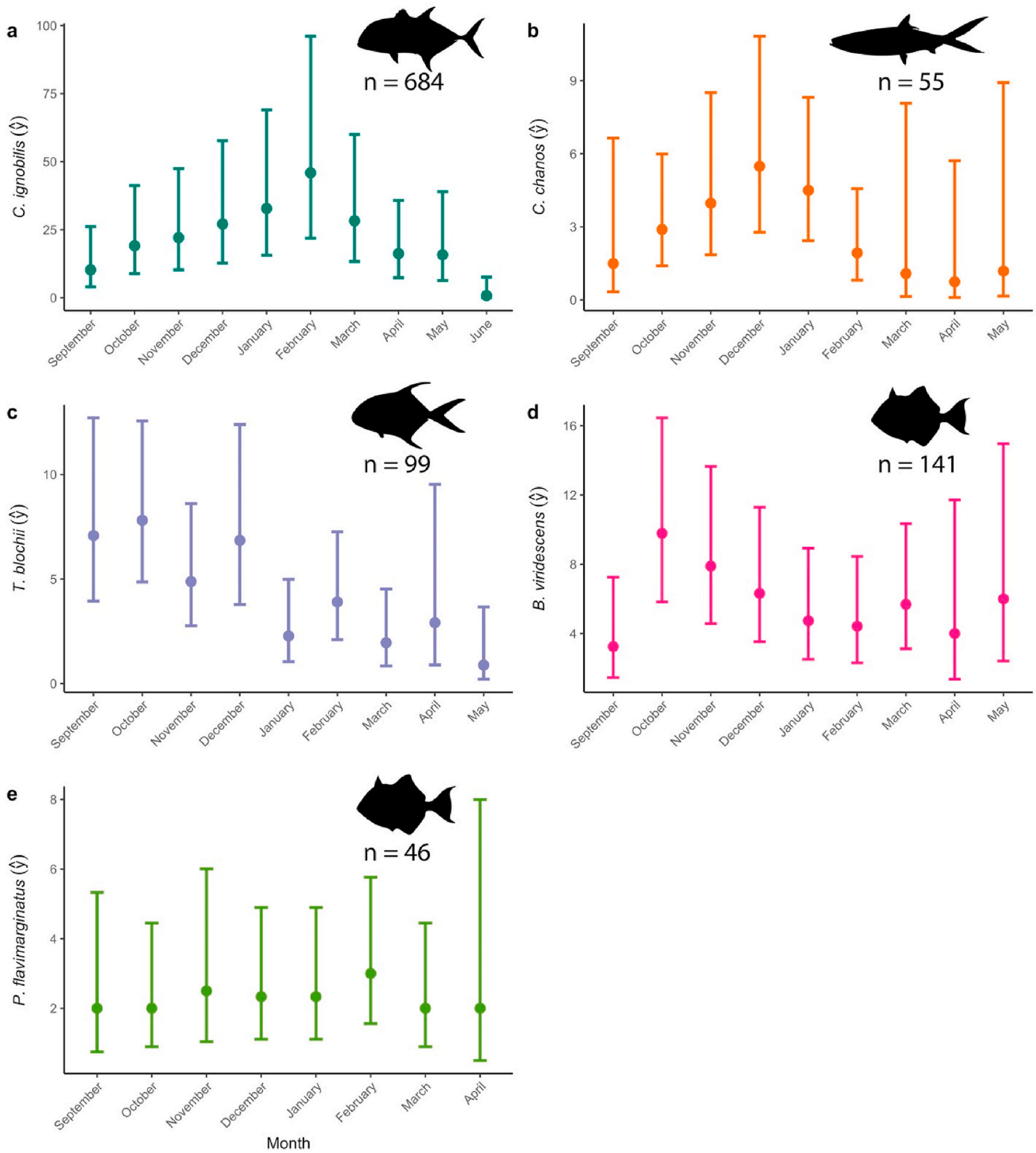

Fig. 3. Predicted monthly catch counts and associated 95% confidence intervals for each species derived from generalized linear mixed model (GLMM) count models.

intersects with fishing pressure. Further, in early 2020, based on movement tracking data and preliminary catch data, AFC and ICS agreed to close down two separate high-pressure fishing locations to experimentally examine and quantify the role of closures may have on the fishery. In the end, coordinated efforts in fundraising, logistics and other in-kind support, and working directly with the people that use the resources have been invaluable to implementing additional scientific approaches surrounding C&R research.

4.2. Considerations and recommendations

While this initiative and its monitoring program was successful in advancing research and evidence-based management (e.g., reducing daily angler capacity, designing, implementing, and evaluating closures, and strict adoption of C&R code of conduct) to reach a more sustainable fishery on Alphonse Group, some considerations are useful to acknowledge for similar endeavors in the future. Since anglers are paired with experienced and trained guides on Alphonse Group, catch rates are expected to remain fairly consistent across visiting angler groups, thus, catch logs are an ideal method to monitor and understand these more specialized fisheries from year to year (Cooke et al., 2000; Kerr 2007). However, there are limitations related to documenting catches when their rates exceed a threshold and it becomes too cumbersome to record. For example, on Alphonse Group, while *A. glossodonta* are one of the top targeted species and catch data would help to monitor the health of this fishery into the future, no data was collected relative to the other five main targeted species since daily catch numbers were extremely high. To implement *A. glossodonta* monitoring on Alphonse Group, alternative methods, e.g., seine nets or traditional-style artisanal fish traps (Boucek et al., 2019; Filous et al., 2021), could be paired with coarse catch log estimates. Further, while number of fish caught provided relevant data for management, quantifying fishing effort (e.g., modified catch logs to record number of daily fishing guests, their own and their guide expertise level, and their proportion of daily effort across target species) would also benefit this and similar monitoring programs so catch per unit effort could be directly

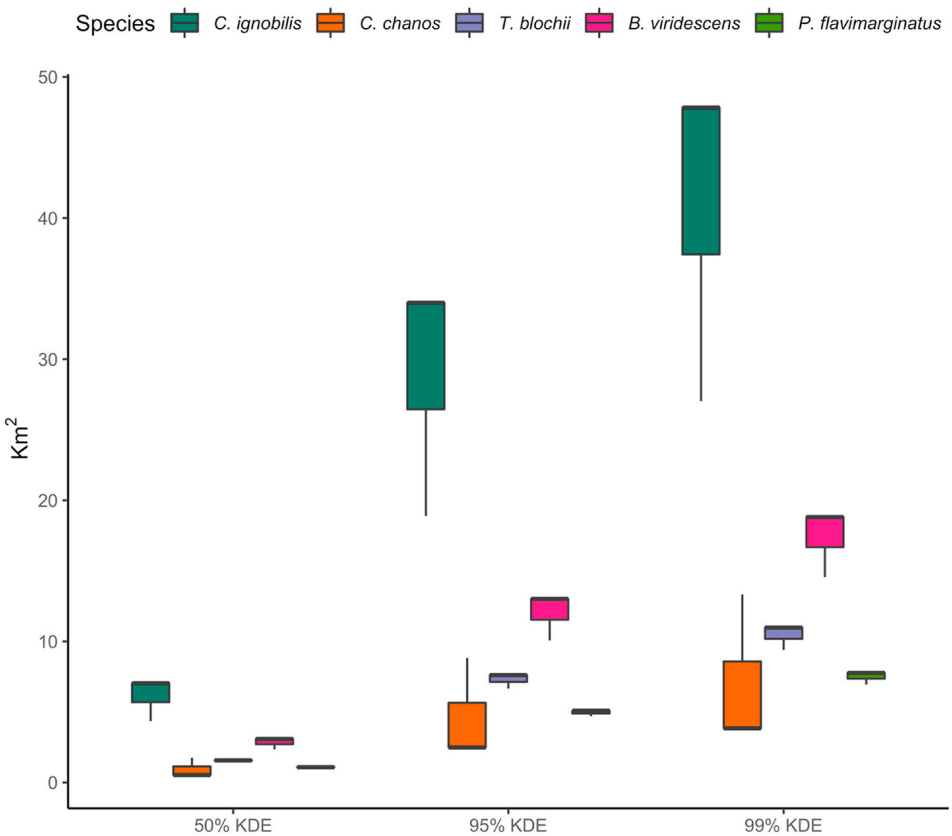

Fig. 4. Catch area (km^2) kernel density estimations (KDEs, 50%, 95%, and 99%) for the five species included in the monitoring program for all fishing seasons combined. Median indicated by the horizontal line and first and third quartiles (the 25th and 75th percentiles) indicated by whiskers within each boxplot.

calculated. Deriving effort spatially would also be useful even when fish are not caught, since angler pressure may still potentially alter fish behavior, e.g., become 'educated', hook shy, or via boat noise cues (Jacobsen et al., 2014; Lennox et al., 2017a). These spatially linked data can ultimately be used to guide focused habitat protection (Black et al., 2015) or to inform recreational fishing carrying capacity (Palomo and Hernández-Flores 2020). In addition to identifying monitoring needs, it is critical to have high levels of participation from the fishing guides and anglers that interact with the fishery on a daily basis. Ultimately, guides and anglers must understand and complete monitoring protocols in their entirety to avoid potential biases related to data processing, analysis, and interpretation.

To improve participation and ensure sound data collection, it would benefit similar initiatives to fully and regularly communicate the significance of the monitoring program and how it directly benefits the resource and, thus, their livelihoods (Cooke et al., 2000). Since anglers on Alphonse Group were typically transient clients, it was critical that fishing guides were fully informed through presentations and one-on-one conversations, so that, in turn, they could effectively advocate and communicate with their clients on why extra time was spent to correctly fulfill monitoring procedures. In addition, AFC management required data collection by guides and routinely reinforced the importance of it. However, depending on the monitoring procedure and its duration (e.g., waiting for a fish to be measured), some clients were found to become agitated or impatient, especially if their fishing time was jeopardized due to lengthy protocols or fish welfare was an issue. This was especially apparent when guests may have not been provided sufficient information regarding the program, or did not care for it. Thus, data collection can be inhibited because of competing demands with monitoring programs, such as fishing time, and this is especially problematic when guides are heavily compensated through tipping practices that are based on the experiences they provide their clients.

Beyond data collection, it is also critical for stakeholder initiatives to recognize the complexity behind data processing and analytics, and to find partners with adequate expertise to fully interpret the findings and to build upon the existent program with scientific rigor. Here, in Alphonse Group, AFC, BSS, AF, and ICS decided to extend this collaboration to multiple academic institutions and organizations to help process, analyze, and detect any concerning trends within their fisheries. In this way, this initiative provides an excellent example of how each partner plays an integral role including identifying potential problems and management needs, proposing and implementing precautionary management practices (i.e., code of conduct) and monitoring programs, and to data analysis and interpretation. Such initiatives may lead to formal co-management structures that benefit multiple stakeholder groups and help to advance economic prosperity while establishing sound management and conservation strategies.

4.3. Conclusion

As the Republic of Seychelles takes steps to improve marine conservation (such as the 30% designation of Seychelles EEZ in 2020 as marine protected areas including several Outer Islands), more focus will be needed on recreational fisheries, especially C&R recreational fisheries that are often perceived as low-impact and not causing environmental harm. Here, we provide an example of a successful monitoring initiative developed between a local fishing operation and NGO in an attempt to ensure the sustainability of an emerging C&R fishery on the atolls of Alphonse Group. Collected from spatially explicit catch logs, this cooperative program revealed that *C. ignobilis*, *T. blochii*, and *B. viridescens* catch counts have increased while catch counts have decreased for *C. chanos* and *P. flavimarginatus*. In addition, catches varied from month-to-month and by location for each species, providing the foundation for additional scientific research and new insights into

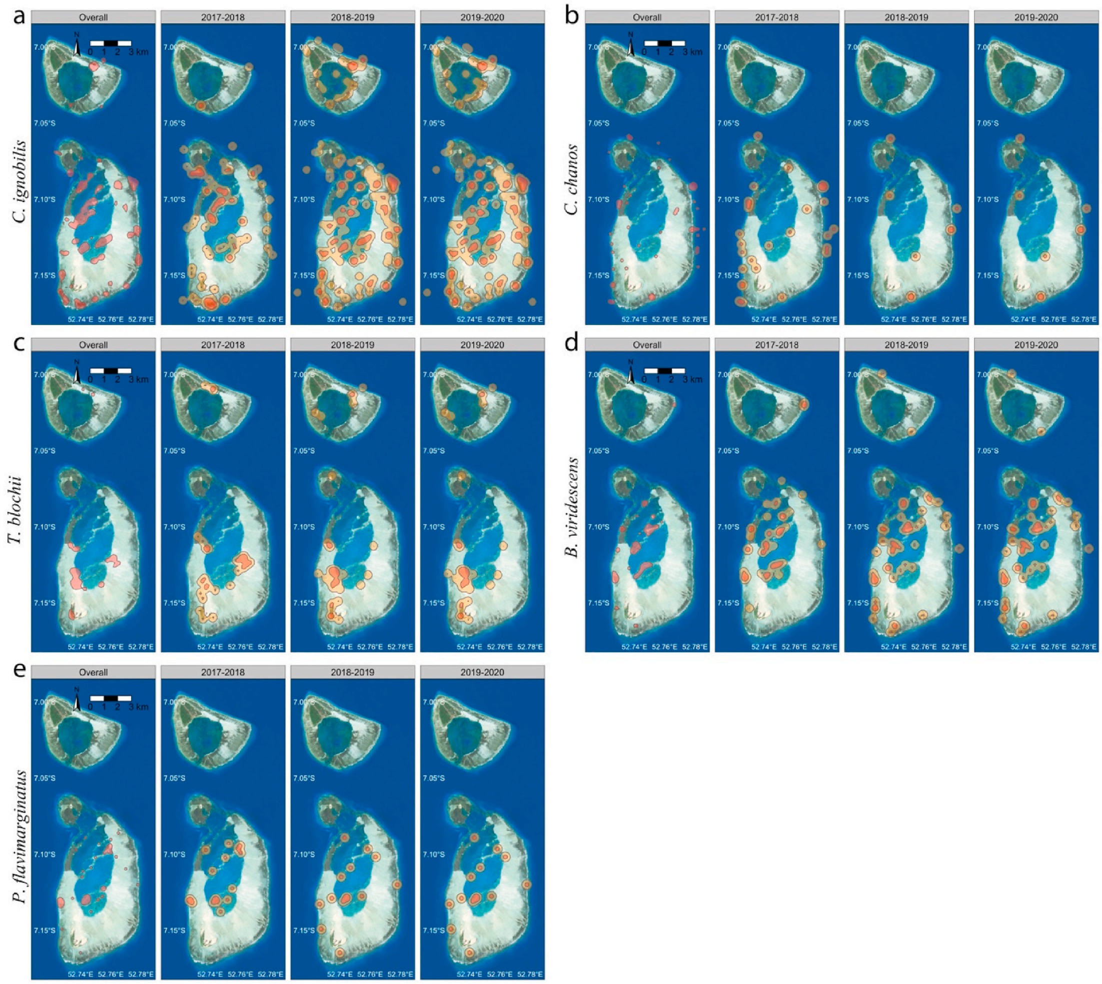

Fig. 5. Catch data kernel density estimations (KDEs) for a) *C. ignobilis*, b) *C. chanos*, c) *T. blochii*, d) *B. viridescens*, and e) *P. flavimarginatus*. 95% and 50% KDEs displayed as orange and red, respectively. The first panel of each species plot represents the overall 50% catch data KDE, subsequent panels indicate the 50% and 95% catch data KDEs for each season. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Proportion of catch data area overlap for 95% (a) and 50% (b) kernel density estimations (KDEs) measured as the proportion of species *i*'s (side/row) KDE that is overlapped by species *j*'s (top/column) KDE.

a)					
	C. ignobilis	C. chanos	T. blochii	*B. viridescens*	P. flavimarginatus
C. ignobilis	1.00	0.72	0.52	0.63	0.41
C. chanos	0.87	1.00	0.50	0.73	0.51
T. blochii	0.95	0.74	1.00	0.74	0.60
B. viridescens	0.91	0.88	0.59	1.00	0.60
P. flavimarginatus	0.96	1.00	0.79	0.98	1.00
b)					
C. ignobilis	1.00	0.42	0.36	0.44	0.39
C. chanos	0.45	1.00	0.18	0.21	0.09
T. blochii	0.93	0.43	1.00	0.50	0.57
B. viridescens	1.00	0.44	0.44	1.00	0.69
P. flavimarginatus	1.00	0.21	0.57	0.79	1.00

fishing capacity and sustainability. With the collaboration among the private tourism sector, NGOs, and academic research institutions, conversations surrounding the management of recreational fisheries across the entire Outer Island Groups of Seychelles has begun with a new appreciation for evidence-based and collaborative management.

Contributors

GF, GC, CN, JN, CM, KR, and DM acquired data. LG analyzed the data. LG, AJ, SC interpreted the data and wrote the manuscript. All authors contributed to drafting and revising the manuscript. All authors approved the final article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2021.105681.

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