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Underwater assessments revealed a ray-dominated assemblage in the elasmobranch reef communities along Sabah's coastal waters

UNIVERSIDADE DO ALGARVE

Faculdade de Ciência e Tecnologia

2022

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Mestrado em Biologia Marinha

Underwater assessments revealed a ray-dominated assemblage in the elasmobranch reef communities along Sabah's coastal waters

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Faro, Portugal, 2022

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RESUMO

Os elasmobrânquios, também conhecidos como Chondrichthyes (peixes cartilagíneos), são compostos por tubarões, raias, patas e quimeras. Durante as últimas décadas, a procura global de produtos de tubarão (barbatanas, guelras, carne, cartilagem) levou a uma sobreexploração causando uma enorme queda da diversidade e abundância de elasmobrânquios. Paralelamente disso, a expansão e urbanização da costa estão a induzir mudanças comportamentais e destruição de habitats das espécies costeiras. Sendo estas K - espécies selecionadas (longa duração, baixo número de descendentes, maturidade sexual tardia, etc...), são sensíveis à degradação dos seus ecossistemas e à sobrepesca. De facto, como consequência da sobrepesca, a maioria das espécies de elasmobrânquios são agora consideradas em perigo ou ameaçadas.

No Estado de Sabah (ilha de Bornéu, Malásia), os elasmobrânquios são consumidos localmente ou exportados para os principais mercados estrangeiros (Singapura, Hong Kong e China), onde a sopa de barbatanas de tubarão é considerada uma importante iguaria. Os elasmobrânquios não são espécies alvo das pescarias, sendo capturados principalmente como capturas acessórias ("*bycatch*") em redes de arrasto e redes de deriva. No entanto, os pescadores da pesca artesanal ou pequena pesca retêm-nos quando os capturam, uma vez que estes representam uma fonte extra de rendimento. No âmbito do consumo local, o povo malaio utiliza todo o corpo dos elasmobrânquios, quer para alimentação (carne e barbatanas, diferentes formas de consumo), quer para cuidados pessoais (cartilagem, dentes, maxilares). Em 2016 foi elaborado na Malásia um Plano Nacional de Ação para os tubarões (NPOA-Sharks), que visa promover a sua conservação, gestão e sensibilização através de 7 itens principais. Em 2014, o NPOA-Shark foi melhorado e, este verão, quando estive na Malásia, o meu orientador local participou num simpósio com o objetivo de escrever o NPOA-Shark 2. Apesar da fiscalização da pesca, a Malásia, e especialmente o estado de Sabah, continua a ser um importante mercado asiático para o comércio de barbatanas de tubarão. Estudos nacionais realizados na última década mostraram que a maioria dos pescadores da pequena pesca são contra a proibição total da pesca de elasmobrânquios, uma vez que esta faz parte do seu modo de vida e da alimentação local.

O objetivo do presente estudo é avaliar a abundância e a riqueza específica das populações de elasmobrânquios em diferentes locais do estado de Sabah. A área principal de análise foi o Parque Tunku Abdul Rahman (TARP), a Área Marinha Protegida (AMPs) mais antiga do país. Foram

também consideradas outras AMPs. Comparações entre abundância e riqueza específica foram realizadas para as águas protegidas e não protegidas adjacentes aos limites das AMPs consideradas. Para realizar esta tarefa, foram efetuadas observações utilizando câmaras de vídeo iscadas (*Baited Remote Underwater Video Systems* - BRUVS) e censos visuais subaquáticos (*Underwater visual census* - UVC). As zonas de amostragem localizaram-se nas linhas de costa de Sabah e incluíram três Áreas Marinhas Protegidas , incluindo o TARP, e duas áreas sem estatuto de proteção. Pretendeu-se com este estudo investigar a eficácia do TARP e verificar se uma AMP multiuso é suficiente para a conservação e a gestão adequada das populações de elasmobrânquios que ocorrem dentro de suas fronteiras. As abundâncias relativas e a riqueza específica foram estimadas e analisadas. Além disso, os objetivos deste estudo incluíram ainda a avaliação dos fatores que influenciam as populações de elasmobrânquios, tais como profundidade, visibilidade ou tipo de fundo.

Os BRUVS foram lançados a partir do barco nos locais de amostragem, sendo separados por, pelo menos, 200-300 metros dos locais de UVC, de forma a evitar que elasmobrânquios individuais fossem atraídos pelo isco e, por isso, registados nos censos visuais subaquáticos. O isco foi comprado na manhã anterior à sessão de campo, para garantir a frescura, e a mistura foi preparada a bordo. Para as amostragens com UVC, e uma vez que é particularmente difícil avaliar os elasmobrânquios durante a realização de um transecto (eles fogem dos mergulhadores), foi utilizada uma metodologia padronizada, em que , os mergulhadores registaram espécies e abundâncias durante 3 minutos (correspondente a uma distância de 50 metros), seguindo uma direção linear e mantendo-se à mesma profundidade. Trata-se de um método semelhante ao método de transecto de cintura utilizado em diferentes estudos de elasmobrânquios, em que os mergulhadores seguem um transecto e registam os indivíduos avistados. No presente caso, os mergulhadores nadaram muito lentamente, a menos de 1m por segundo, perto do fundo. De forma a minimizar a perturbação devido à presença do mergulhador, foi feito um intervalo de pelo menos 20 metros ou poucos minutos a nadar antes de iniciar outro registo de transectos. Para cada transecto, as espécies observadas e a cobertura do fundo (percentagem de recifes de coral, areia, rocha e rublos) foram registadas numa placa de registo subaquática.

Foram observados um total de 86 elasmobrânquios de oito espécies (cinco de tubarões e três de raias). As raias representaram 69,7% (n=60) dos avistamentos, e os tubarões 30,3% (n=26). Duas espécies de raias com manchas azuis (*Taeniura lymma*, n=41, 47,7% e *Neotrygon orientalis*, n=17, 19,8%) foram identificadas como as espécies mais abundantes. A espécie de tubarão mais abundante foi o *Carcharhinus melanopterus*, com 11 indivíduos registados. A maioria dos elasmobrânquios foram observados nas AMPs (n=73 indivíduos). Apenas 13 elasmobrânquios foram avistados nas áreas sem estatuto de proteção, oito indivíduos em PPP e cinco indivíduos em PS. O TARP parece ser o local com a maior abundância e riqueza específica de elasmobrânquios (n=49, nove indivíduos pertencentes ao grupo dos tubarões e 40 às raias). Foram construídos quatro gráficos de caixa para representar a abundância e a riqueza específica, por grupo de localização (três grupos: TARP, outras AMPs e zonas fora das AMPs). Os gráficos de caixa foram construídos por profundidade: águas pouco profundas de 0 a 12m de profundidade e águas profundas de 12m a 36m de profundidade (o mais profundo dos transectos).

Realizamos duas Análises de Componentes Principais (PCA) para analisar a abundância e riqueza específica dos elasmobrânquios. Alguns parâmetros foram testados para avaliar o seu efeito sobre as duas variáveis. A visibilidade foi claramente o fator mais importante a influenciar a abundância e a riqueza específica. A proporção do fundo com recife de coral foi o segundo factor com maior impacto. De facto, o maior número de elasmobrânquios foi observado no fundo de recife de coral, quando comparado com o número de indivíduos observado em fundo de areia ou cascalho. A tabela da Análise Fatorial de Correspondência (FCA) mostra onde uma espécie foi mais observada em função das três diferentes localizações. ta De acordo com esta análise, tal como nos resultados obtidos para a abundância e a riqueza específica, verificou-se a existência de uma quantidade significativa de transectos onde não se observou nenhum elasmobrânquio. Para as duas espécies de raias com manchas azuis (*Taeniura lymma* e *Neotrygon orientalis*), as duas espécies de elasmobrânquios dominantes deste estudo, o TARP é o local de amostragem onde o maior número de exemplares foi avistado. Paralelamente, estas são as duas únicas espécies encontradas nas três localizações diferentes, mostrando uma distribuição generalizada dentro das águas de Sabah. Paralelamente, o tubarão do recife de ponta preta (*Carcharhinus melanopterus*), a espécie de tubarão mais comum do estudo, também foi avistado apenas nas AMPs. Os resultados apresentados comprovam a importância das AMPs para a conservação dos elasmobrânquios. No que diz respeito à abundância de elasmobrânquios, o TARP é o local onde a maioria dos indivíduos foi observada, o que se deve relacionar com o maior número de mergulhos (portanto, transectos e avistamentos) em relação a qualquer outro local.

Na generalidade verifica-se que a abundância de elasmobrânquios é maior para o TARP do que para qualquer um dos outros locais de amostragem, principalmente porque o número de transectos não é o mesmo. Quando comparamos os indivíduos do grupo de elasmobrânquios avistados, verifica-se que a abundância nas águas profundas do TARP é menor do que nas outras duas AMPs, mas, em geral, é maior em relação às águas desprotegidas. Esses resultados estão de acordo com estudos anteriores, mostrando a importância das AMPs e santuários de tubarões para sua conservação.

ABSTRACT

Over the last decades, elasmobranch populations have been in decline globally, due to various pressures induced by human beings (illegal ways of fishing and abuses, urbanization and expansion of the coastal areas, pollution run-offs and destruction of the marine environments and habitats). This study aimed to analyze the conservation efficiency of some Marine Protected Areas (MPA) in Borneo (State of Sabah, Malaysia) for elasmobranchs, with a particular focus on the *Tunku Abdul Rahman Park* (TARP). Underwater Visual Census (UVC) and Baited Remote Underwater Cameras (BRUVs) were the techniques used to assess and quantify the elasmobranch diversity and abundance.

A total of 48 dives were conducted, where 86 individuals from 8 different elasmobranch species were sighted. Box-plots of the abundance and the specific richness of elasmobranchs were constructed, dividing the transects by depth and location. The Kruskal-Wallis tests revealed significanct results for both abundance and specific richness, but only for deep water transects (>12m depth, $p = 0.030$ for abundance, $p = 0.0309$ for specific richness). Two species of blue-spotted rays (*Taeniura lymma*, n=41, 47,7% and *Neotrygon orientalis*, n=17, 19,8%) appeared as the most dominant species, corroborating the findings of earlier studies in TARP and other MPAs in Sabah. Correlation circles (PCA) and Factorial Correspondence Analysis (FCA) exposed the importance of the MPAs in term of conservation of elasmobranchs in the State of Sabah. Yet, the elasmobranch populations are low in abundance, mostly due to the commercialization of elasmobranchs in Malaysia. It is urgent to conduct further regular studies in Borneo and keep implementing the National Plan of Action for Sharks (NPOA-Shark), to improve elasmobranch conservation and enforcement of conservation measures.

ACKNOWLEDGEMENTS

First of all, I would like to express my gratitude to the Borneo Marine Research Institute (BMRI) and Sabah Parks to host me during my stay on the Borneo island. A special thanks is going to my two supervisors there : Dr B. Mabel Manjaji-Matsumoto and Dr Nasrulhakim Maidin, without whom I could not do much. Without them, my whole internship and study in Sabah would have been totally different. The daily help they gave me and the favors they granted to me were priceless and I will remember that. Another thanks goes to the Sabah Parks staff based on Pulau Manukan (TARP), especially Mr Elvin, Awang, that were supportive for the logistic, and Jack and Boh, my diving buddies. I also acknowledge the people from the Tropical Research and Conservation Center (TRACC) of Pulau Pom-Pom to let us come and undertake our experiment with them. I would also like to thank Dr Karim Erzini, which was more than helpful for the preparation part in Faro, the writing of the research proposal and the final thesis report, and provided me some cameras for the field trip sessions in Borneo.

Then, I would like to thank two different groups of amazing people : the Pyramid and Briscolina. Scientists belonging to the next generation, full of ambition and with different dreams, which provided a daily support during my whole education in Paris and Faro. I will be always grateful to meet such people. A special thanks to Maylis for the advices through the whole writing process.

Finally, I would like to give credit to my parents for introducing me to scuba-diving almost 15 years ago. Thanks to them, I discovered a whole new world, the underwater world, which became quickly my passion and fulfilled me of ambitions. Without this experience, my journey would not have been the same until now and I cannot be more grateful for this.

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i. Lis of Abbreviations

- **NPOA-Sharks** : National Plan Of Action for sharks

- **IUCN** : International Union for Conservation of Nature

- **CITES** : Convention on International Trade in Endangered Species

Location and study sites (Pulau = island in Bahasa Maleyu, the Malaysian language)

- **TARP** : Tunku Abdul Rahman Park
- **PTMP** : Pulau Tiga Marine Mark
- **PSMP** : Pulau Sipadan Marine Park
- **PS** : Pulau Sepanggar
- **PPP** : Pulau Pom-Pom

Methods

- **BRUVS** : Baited Remote Underwater Video Systems
- **UVC** : Underwater Visual Census

Statistical analysis

- **PCA** : Principal Component Analysis
- **FCA** : Factorial Correspondence Analysis

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iii. General Introduction

Elasmobranchs, also known as *Chondrichthyes* (cartilaginous fishes), are composed of the sharks, rays, skates, and chimaeras (Stevens et al., 2000 ; Last et al., 2010). During the last decades, the global demand for shark products (fins, gills, meat, cartilage) have led to overexploitation causing a huge decline of elasmobranch diversity and abundance (Assad et al., 2018 ; Jaiteh et al., 2017). In addition, coastal expansion and urbanization are inducing behavioral changes and the destruction of the habitats of the coastal species (Goetze & Fullwood, 2013). Being *K – selected* species (long lifespan, low number of offspring, late sexual maturity, etc...), they are sensitive to the degradation of their ecosystems and overfishing (Springer, 1967 ; Ali et al., 2018 ; Vianna et al., 2018 ; Worm, et al., 2013). As a consequence of the overfishing, most of the elasmobranch species now, are considered endangered or threatened (Burgess et al., 2005 ; Dulvy et al., 2014 & 2017).

The Southeast Asian region has been recognized as a hotspot for marine life biodiversity, called the Coral Triangle. It is composed of the Exclusive Economic Zones (*EEZ*) of six different nations : The Philippines, Malaysia, Indonesia, Timor-Leste, Solomon Islands and Papua New Guinea (Asaad, et al., 2018 ; Veron et al., 2011). The level of biodiversity of the Coral Triangle is one of the richest on Earth (Allen, 2008 ; Ali et al., 2018), due to a complex geological history (tectonically unstable since the Eocene ; Goetze & Fullwood, 2013 ; Arai, 2015) and ocean circulation that led to isolation and speciation (Allen, 2008 ; Bowen et al., 2013). The Coral Triangle hosts 37% of reef fish (Allen, 2008) where high levels of endemism are reached (Manjaji-Matsumoto et al., 2018 ; Veron et al., 2011).

Elasmobranchs are not targeted, but mostly caught as bycatch using trawlers and drift nets (Noh et al., 2019). But, small-scale fishermen still keep them when they fish some, as it is an extra source of income for the fishermen (Ahmad et al., 2017 & 2020 ; Dent & Clarke, 2015). In the State of Sabah (Borneo island, Malaysia), elasmobranchs are either locally consumed or traded abroad to the main final hubs (Singapore, Hong Kong and China) where the shark fin soup is considered a great delicacy (Dent & Clarke, 2015 ; Fatimah et al., 2017). For the local consumption, Malaysian people are using the whole body of the elasmobranchs, either for food (meat and fins, different ways of consumption) or for personal care (cartilage, teeth, jaws) (Ismail et al., 2019 ; Noh et al., 2019 ; Friedman et al., 2018). The marketing networks are quite elaborate, with various actors : fishermen, retailers, wholesalers, importers/exporters and final consumers. The demand for elasmobranch products has increased during the last decades, and the supply sector cannot meet the demand from consumers (Stevens et al., 2000 ; Worm et al., 2013).

In the face of rapid human population growth, poaching and habitat destruction, there is an urgent need to conduct monitoring programs to detect changes in biodiversity (Hoyt, 2014 ; Heithaus et al., 2008 ; Goetze & Fullwood, 2013 ; White et al., 2013). The creation of Marine Protected Areas (MPAs) and shark sanctuaries can be one of the different techniques to manage fisheries and their environment's health (Heithaus et al., 2008 ; Claudet et al., 2008). MPAs must have established plans of actions and objectives (Knip et al., 2012 ; Fowler, 1997 ; Speed et al., 2016), either ecological (protect the habitats and maintain the fish populations viable) or economic and social (enhancement of the fisheries, ecotourism, or education) (BüNFlL, 1997). Global reports affirm that some reef-species abundances are increasing within MPA's borders, due to high site fidelity (MacNeil et al., 2020 ; Goetze & Fullwood, 2013). The implementation of no-take reserves with strong enforcement is providing shelters and a greater amount of prey, which benefits every life stage of elasmobranchs (Goetze & Fullwood, 2013 ; Speed et al., 2016 & 2018).

Elasmobranchs are however much less protected, as most of the species on the IUCN Red-List (International Union for Conservation of Nature) do not have or have partially their home ranges within no-take MPAs (Dulvy et al., 2014 & 2017). Most of the emblematic species are protected under IUCN and CITES (Convention on International Trades of Endangered Species) lists and are predominantly large body, pelagic species with high migratory patterns (Friedman et al., 2018 ; Jaiteh et al., 2017). Of theses species, studies have shown that the most susceptible species to decline are coastal species, despite the enforcement of their conservation (Friedman et al., 2018 ; Dulvy et al., 2014 ; Martin et al., 2020). The coastal elasmobranch species are primarily impacted by overfishing and the numerous coastal activities, including water run-off from land-based activities resulting in marine pollution.

In Malaysia, a National Plan Of Action for sharks (NPOA-Sharks) was elaborated in 2006 to increase their conservation, management and awareness through 7 major items (Ismail et al., 2019). The important items they discussed are the following : biology and habitat, the socioeconomic aspects of the fishermen, the trade and consumption of elasmobranchs, the capacity building and the research coordination, the raising of awareness through actions and information, and the conservation and proper management of elasmobranchs (Ismail et al., 2019). In 2014, this NPOA-Shark was ameliorated and this summer, when I was in Malaysia, my local supervisor participated in a symposium to write the NPOA-Shark 2. Despite fisheries enforcement, Malaysia still remains a massive Asian trader of shark fins, especially the state of Sabah (Noh et al., 2019). National surveys carried out within the last decade showed that a majority of the small-scale fishermen are against a total ban of elasmobranch fisheries, as it is a part of their livelihood and local food (Ahmad et al., 2017 ; Noh et al., 2019).

It is fundamental to observe the movement patterns and the spatial distribution of elasmobranchs linked with the boundary of MPAs to make assumptions on their behaviors and increase their conservation (Albano et al., 2021 ; MacNeil et al., 2020 ; Goetze & Fullwood, 2013). Baited Remote Underwater Video Systems (BRUVS) are nowadays the most common tool used for this (Sherman et al., 2018). Underwater Visual Census (UVC) can also be used to maximize our chances to sight elasmobranch individuals by combining two different methods.

The methods used to conduct surveys are not perfect and possess some bias. First of all, there is a spatial and temporal scale that we need to take into account (Langlois et al., 2010). Most of the records were during daytime, as the light will not let us perform our tasks properly during night time. But it is well known that most elasmobranchs forage during early morning and the night (Last et al., 2010 ; McCauley et al., 2012). Additionally, a record of one hour at a certain depth is not representative of the behavior of the individuals during the whole day (Langlois et al., 2010). Certain species might adopt philopatric behavioral patterns and stay outside the borders of the MPA during the day but come back during the night to forage or mate (or the opposite pattern) (White et al., 2013 ; Osgood et al., 2019). The same spatial distribution can happen with depth, going deeper during the day and then going towards the surface or inside lagoons to hunt. Therefore, there is a possibility that we did not assess the whole population of certain species. It is vital to perform surveys at any time of the day in all the different sampling sites of the MPAs, at any depth, to have a strong overall data collection in further studies. Also, both methods are weather dependent : for both diving and underwater records, if there is turbidity (due to run-offs, currents or monsoons) the accuracy of the surveys will decrease (Willis et al., 2000 ; White et al., 2013). Current circulation has also disturbed the survey process, as a drift dive can be more complex (White et al., 2013). Performing surveys while diving can alter the behavior and the density estimations of the elasmobranchs present in the area (Willis et al., 2000 ; White et al., 2013 ; McCauley et al., 2012).

Some individuals will be curious and attracted by the divers, and some can be the opposite and leave the area. This might imply some bias if the divers did not count them yet. Thus, it is important to consider the life history and the biogeographic patterns of the target species before choosing the gear (White et al., 2013).

From all the literature comparing UVC and BRUVS use, only one study recommends the use of UVC over BRUVS (Stobart et al., 2007). The main advantage of UVC over BRUVS is the mobility of the diver (White et al., 2013). The transect belt method allows the diver to cross different territories and spot species in hidden areas (Langlois et al., 2010 ; Colton & Swearer, 2010). It also covers a wider range of habitats compared to the BRUVS and gives access to places where the structures would not be able to go (Langlois et al., 2010 ; Colton & Swearer, 2010). Belt transects are providing the most reliable density estimates of all the diving methods, while the stationary counting methods provides the highest density estimates (McCauley et al., 2012). Even if in some studies data and species richness are higher with UVC than BRUVS (Colton & Swearer, 2010), the majority of the conducted studies recommend the use of BRUVS to assess abundance of target species, like elasmobranchs (Gore et al., 2020 **;** McCauley et al., 2012 ; Osgood et al., 2019 ; Colton & Swearer, 2010 ; Langlois et al., 2010 & 2018 ; Speed et al., 2016 ; McNeil, et al., 2020 ; White et al., 2013 ; Willis et al., 2000 ; Last et al., 2010 ; Sherman et al., 2018). In the study of Colton & Swearer (2010)*,* the UVC surveys recorded more individuals and more diversity in the species distribution, but they still recommend the use of BRUVS to assess mobile apex predators. Still, in heavily dived environments, reef sharks do not avoid divers or alter their spatial distribution and abundance compared to undived sites (Bradley et al., 2017). Moreover, it seems that there are no long-term effects on their behavior, since they are used to the presence of divers.

The use of BRUVS allows us to detect large mobile species and is appropriate for long-term study (Brooks et al., 2011). Using baited cameras also helps to not interfere with both attracted individuals and benthic environment (Brooks et al., 2011 ; Osgood et al., 2019). In most of the studies, the species richness and the total number of individuals will be higher with BRUVS than UVC (Colton & Swearer 2010 ; Langlois et al., 2010 & 2018 ; Willis et al., 2000). Still, the use of BRUVS has some bias. As said previously, the main disadvantage of *BRUVs* is the non-mobility capacity compared to divers. BRUVS methods tend to underestimate territorial species, as if the structure is not sunk within the borders of the species' territory, we might not be able to record it (Colton & Swearer, 2010). There is also a matter of elasmobranch personality with this method.

Some are going to be attracted by the bait, but it might happen that some individuals are avoiding the bait (Langlois et al., 2010).

The aim of this study is to assess the abundances and specific richness of elasmobranch populations, at different locations in the state of Sabah. The main focus was the *Tunku Abdul Rahman Park* (TARP), the oldest MPA of the country. Comparisons of the abundance and specific richness was conducted between the protected and unprotected waters adjacent to the boundaries of the MPAs. To perform this task, observations were carried out using baited underwater cameras (BRUVS) and with scuba diving census (UVC). The sampling areas were along the Sabahan coastlines, with 3 MPAs, including the TARP, and 2 non-MPA areas. The purpose is to investigate the effectiveness of the TARP and see if a multi-use MPA is sufficient for the proper conservation and management of elasmobranch populations within its borders. The relative abundances and specific richness will be estimated and analyzed. Moreover, the objectives of the study include the evaluation of the factors influencing the elasmobranch populations, such as depth, visibility or the bottom type.

iii. References of the General Introduction

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MANUSCRIPT OF THE PAPER

Underwater assessments revealed a ray-dominated assemblage in the elasmobranch reef communities along Sabah's coastal waters

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Abstract :

Over the last decades, elasmobranch populations have been in decline globally, due to various pressures induced by human beings (illegal ways of fishing and abuses, urbanization and expansion of the coastal areas, pollution run-offs and destruction of the marine environments and habitats). This study aimed to analyze the conservation efficiency of some Marine Protected Areas (MPA) in Borneo (State of Sabah, Malaysia) for elasmobranchs, with a particular focus on the *Tunku Abdul Rahman Park* (TARP). Underwater Visual Census (UVC) and Baited Remote Underwater Cameras (BRUVs) were the techniques used to assess and quantify the elasmobranch diversity and abundance.

A total of 48 dives were conducted, where 86 individuals from 8 different elasmobranch species were sighted. Box-plots of the abundance and the specific richness of elasmobranchs were constructed, dividing the transects by depth and location. The Kruskal-Wallis tests revealed significanct results for both abundance and specific richness, but only for deep water transects (>12m depth, $p = 0.030$ for abundance, $p = 0.0309$ for specific richness). Two species of blue-spotted rays (*Taeniura lymma*, n=41, 47,7% and *Neotrygon orientalis*, n=17, 19,8%) appeared as the most dominant species, corroborating the findings of earlier studies in TARP and other MPAs in Sabah. Correlation circles (PCA) and Factorial Correspondence Analysis (FCA) exposed the importance of the MPAs in term of conservation of elasmobranchs in the State of Sabah. Yet, the elasmobranch populations are low in abundance, mostly due to the commercialization of elasmobranchs in Malaysia. It is urgent to conduct further regular studies in Borneo and keep implementing the National Plan of Action for Sharks (NPOA-Shark), to improve elasmobranch conservation and enforcement of conservation measures.

Keywords : Elasmobranchs, Baited Remote Underwater Video Systems (BRUVS), Underwater Visual Census (UVC), Marine Protected Areas (MPA), Conservation management, Abundance and Specific richness.

1. <u>INTRODUCTION</u>

Elasmobranchs, also known as *Chondrichthyes* (cartilaginous fishes), are composed of the sharks, rays, skates, and chimaeras (Stevens et al., 2000 ; Last et al., 2010). During the last decades, the global demand for shark products (fins, gills, meat, cartilage) have led to overexploitation causing a huge drop of elasmobranch diversity and abundance (Assad et al., 2018 ; Jaiteh et al., 2017). In addition, the coastal expansion and urbanization are inducing behavioral changes and the destruction of the habitats of the coastal species (Goetze & Fullwood, 2013). Being *K – selected* species (long lifespan, low number of offspring, late sexual maturity, etc...), they are sensitive to the degradation of their ecosystems and overfishing (Springer, 1967 ; Ali et al., 2018 ; Vianna et al., 2018 ; Worm, et al., 2013). As a repercussion of the overfishing, most of the elasmobranch species now, are considered endangered or threatened (Burgess et al., 2005 ; Dulvy et al., 2014 & 2017).

The Southeast Asian region has been established as a hotspot for marine life biodiversity, called the Coral Triangle. It is composed of the Exclusive Economic Zones (EEZ) of six different nations : The Philippines, Malaysia, Indonesia, Timor-Leste, Solomon Islands and Papua New Guinea (Asaad, et al., 2018 ; Veron et al., 2011). The level of biodiversity of the Coral Triangle is one of the richest on Earth (Allen, 2008 ; Ali et al., 2018), due to a complex geological history (tectonically unstable since the Eocene ; Goetze & Fullwood, 2013 ; Arai, 2015) and ocean circulation that led to isolation and speciation (Allen, 2008 ; Bowen et al., 2013). The Coral Triangle hosts 37% of reef fish (Allen, 2008) where high levels of endemism are reached (Manjaji-Matsumoto et al., 2018 ; Veron et al., 2011). In the State of Sabah (Borneo island, Malaysia), elasmobranchs are either locally consumed or traded abroad to the main final hubs (Singapore, Hong Kong and China) where the shark fin soup is considered a great delicacy (Dent & Clarke, 2015 ; Fatimah et al., 2017). Elasmobranchs are not targeted, mostly caught bycatch using trawlers and drift nets (Noh et al., 2019). But, small-scale fishermen still keep them when they fish some, as it is an extra source of incomes for the fishermen (Ahmad et al., 2017 & 2020 ; Dent & Clarke, 2015). For the local consumption, Malaysian people are using the whole body of the elasmobranchs, either for food (meat and fins, different ways of consumption) or for personal care (cartilage, teeth, jaws) (Ismail et al., 2019 ; Noh et al., 2019 ; Friedman et al., 2018). The marketing networks are quite elaborated, with various actors : fishermen, retailers, wholesalers, importers/exporters and final consumers. The demand for elasmobranch products is increasing during the last decades, and the supply sector cannot meet the demand from consumers (Stevens et al., 2000 ; Worm et al., 2013).

In the face of rapid anthropic population growth, poaching and habitat destruction, there is an urgent need to conduct monitoring programs to detect changes in biodiversity (Hoyt, 2014 ; Heithaus et al., 2008 ; Goetze & Fullwood, 2013 ; White et al., 2013). The creation of Marine Protected Areas (MPAs) and shark sanctuaries can be one of the different techniques to manage fisheries and their environment's health (Heithaus et al., 2008 ; Claudet et al., 2008). MPAs must have established plans of actions and objectives (Knip et al., 2012 ; Fowler, 1997 ; Speed et al., 2016), either ecological (protect the habitats and maintain the fish populations viable) or economic and social (enhancement of the fisheries, ecotourism, or education) (BüNFlL, 1997). Global reports affirm that some reef-species abundances are increasing within MPA's borders, due to high site fidelity (MacNeil et al., 2020 ; Goetze & Fullwood, 2013). The implementation of no-take reserves with strong enforcement is providing shelters and a greater amount of prey, which benefits every life stage of elasmobranchs (Goetze & Fullwood, 2013 ; Speed et al., 2016 & 2018).

Elasmobranchs are however much less protected, as most of the species on the IUCN Red-List (International Union for Conservation of Nature) do not have or have partially their home ranges under no-take MPAs (Dulvy et al., 2014 & 2017). Most of the emblematic species are protected under IUCN and CITES (Convention on International Trades of Endangered Species) lists and are predominantly large body, pelagic species with high migratory patterns (Friedman et al., 2018 ; Jaiteh et al., 2017). Of theses species, studies have shown that the most susceptible species to decline are coastal species, despite the enforcement of their conservation (Friedman et al., 2018 ; Dulvy et al., 2014 ; Martin et al., 2020). The coastal elasmobranch species are primarily impacted by overfishing and the numerous coastal activities, including water run-off from land-based activities resulting in marine pollution.

In Malaysia, a National Plan Of Action for sharks (NPOA-Sharks) was elaborated in 2006 to increase their conservation, management and awareness through 7 major items (Ismail et al., 2019). The important items they discussed about are the next ones : biology and habitat, the socioeconomic aspects of the fishermen, the trade and consumption of elasmobranchs, the capacity building and the research coordination, the raise of awareness through actions and information, and the conservation and proper management of elasmobranchs (Ismail et al., 2019). In 2014, this NPOA-Shark was ameliorated and this summer, when I was in Malaysia, my local supervisor assisted a symposium to write the NPOA-Shark 2. Despite the enforcement of the fisheries, Malaysia still remains a massive Asian trader of shark fins, especially the state of Sabah (Noh et al., 2019). National surveys carried out within the last decade showed that a majority of the small-scale fishermen are against a total ban of elasmobranch fisheries, as it is a part of their livelihood and local food (Ahmad et al., 2017 ; Noh et al., 2019).

It is fundamental to observe the movement patterns and the spatial distribution of elasmobranchs linked with the boundary of MPAs to make assumptions on their behaviors and increase their conservation (Albano et al., 2021 ; MacNeil et al., 2020 ; Goetze & Fullwood, 2013). Baited Remote Underwater Video Systems (BRUVS) are nowadays the most common tool used for this (Sherman et al., 2018). The use of BRUVS is suited to sight large mobile predators, such as elasmobranchs, and they can be used to quantify their relative abundance (Cappo et al., 2004 ; Bruns & Henderson, 2020 ; Colton & Swearer, 2010). Other advantages of conducting assessments using BRUVS : it is a non-invasive methodology for individuals and benthic environment (Bruns & Henderson, 2020), appropriate for long term standardized surveys (White et al., 2013), adapted to any depth and diversity of underwater environment (Brooks et al., 2011). Moreover, there are no issues in selectivity about the size of the individuals and the gear used, which is not the case with longline or net-based methods where you have to decide about the hooks and meshes (Brooks et al., 2011 ; White et al., 2013). The deployment is also simple, as it just needs to attach some baits, drop the structure underwater and then observe the results after the field session (Bruns & Henderson, 2020). Finally, the staff required does not need to possess strong skills to analyze the recorded data (Brooks et al., 2011).

The aim of this study is to assess the abundances and specific richness of elasmobranch populations, at different locations in the state of Sabah. The main focus was the *Tunku Abdul Rahman Park* (TARP), the oldest MPA of the country. Comparisons of the abundance and specific richness was conducted between the protected and unprotected waters adjacent to the boundaries of the MPAs. To perform this task, observations were carried out using baited underwater cameras (BRUVS) and with scuba diving census (UVC). The sampling areas were along the Sabahan coastlines, with 3 MPAs, including the TARP, and 2 non-MPA areas. The purpose is to investigate the effectiveness of the TARP and see if a multi-use MPA is sufficient for the proper conservation and management of elasmobranch populations within its borders. The relative abundances and specific richness will be estimated and analyzed. Moreover, the objectives of this include the evaluation of the factors influencing the elasmobranch populations, such as depth, visibility or the bottom type.

2. MATERIAL AND METHODS

2.1 Study areas

The *Tunku Abdul Rahman Park* (TARP) is a National Park IUCN Category II, gazetted in 1974, and covers approximately 50 km², offshore Kota Kinabalu (Malaysia, Borneo island, state of Sabah) (*Manjaji-Matsumoto, et al, 2018*). It is composed of 5 islands : *Pulau Gaya, Pulau Sapi, Pulau Mamutik, Pulau Manukan and Pulau Sulug* (Figure 2.1) and is under the jurisdiction of Sabah Parks (https://www.sabahparks.org.my/tunku-abdul-rahman-park). Each island is surrounded by fringing coral reefs, including soft corals, and without significant slopes (25 - 30m depth maximum) (Nyanti et al., 1992 ; Waheed et al., 2018). Sandbank formations are present all along the coastlines of the different islands, seagrass beds are patchy and there are also some mangrove places, particularly on the biggest island *Pulau Gaya* (Townsend, 2015). On the western part of the TARP, slopes are slightly diving into the deep, but not in a steep way (Nyanti et al., 1992 ; Townsend, 2015). On the eastern part of the TARP, some fishermen villages are established and it happens that they may sometimes poach inside the marine park for local consumption (Shah et al., 2016).

The marina of Kota Kinabalu is also situated a few kilometers away and induces a daily heavy boat traffic, either for fishing activities or tourism fluxes (Somaskanthan et al., 2016). Pollution run-offs and rubbish are also coming from industrial activities based in Kota Kinabalu, which is the main city of the State of Sabah. Urbanization, deforestation, pesticide and fertilizer abuses are altering the surrounding environments (Jakobsen et al., 2007). Erosion of several coastal areas in the western part of Sabah has been reported in previous studies (Elias et al., 2012 ; Mohd et al., 2014). Moreover, Kota Kinabalu is considered as one of the major landing sites for fishermen in the state of Sabah (Ahmad et al., 2017 ; Abd Haris Hilmi et al., 2020).

Surveys were undertaken in each of the five islands. Sampling sites must have replicates found outside the TARP (Goetze & Fullwood, 2013), as we want to compare the elasmobranch abundances and specific richness in the same conditions (depth, environment, visibility, etc.). For that, we conducted the same methodology in several areas along the Sabahan coastlines, either protected or not.

Figure 2.1 : Screenshot of the Tunku Abdul Rahman Park (TARP), from a coral reef atlas (https://allencoralatlas.org/). Kota Kinabalu is located 3kms from the TARP on the shore, which leads to daily heavy boat traffic (tourism, shipping and transport).

For this study, five different sampling areas in the whole state of Sabah, including the TARP, were surveyed. Two of them are other marine protected areas : *Pulau Tiga Marine Park* (PTMP) and *Pulau Sipadan Marine Park* (PSMP). Both MPAs are also under the jurisdiction of Sabah Parks. The PTMP (https://www.sabahparks.org.my/pulau-tiga-park) is composed of three islands : *Pulau Tiga, Pulau Kalampunian Damit* and *Pulau Kalampunian Besar* (Figure 2.2). The MPA encompasses 158 km² and is also a National Park IUCN Category II, gazetted in 1978. While Pulau Tiga has similar environmental characteristics as the TARP (slight topography, patchy coral reefs and seagrass beds), it is not the case for Pulau Sipadan (https://www.sabahparks.org.my/sipadan-island-park). It is a remote oceanic island, the only one in Malaysia (Emang et al., 2020), where the slopes become steep just after the plateau that is surrounding the island (Figure 2.3). Coral reefs are growing on the top of a volcanic cone, 600m above the seabed (Emang et al., 2020).

Figure 2.2 and 2.3 : Screenshot of the Pulau Tiga Marine Park (left) and Pulau Sipadan Park (right), from a coral reef atlas (https://allencoralatlas.org/). Note that even if they are facing each other, the scale is not the same (Pulau Tiga Marine Park is more than three times bigger).

In 2004, a no-take zone for fisheries of 168 km² was implemented around the island (Zimmerhackel et al., 2018). Tourism was removed from the island to other close areas (either mainland and islands around PSMP) and a carrying capacity of 120 divers per day was set, to enforce the management of the marine park (Zimmerhackel et al., 2018).

The two last sampling areas are two islands adjacent the MPA's borders. *Pulau Sepanggar* (PS) is located up north the TARP, while *Pulau Pom-Pom* (PPP) is one of the surrounding islands close to Sipadan's MPA (Figure 2.4 and 2.5). Both possess the same environmental characteristics as the TARP (slight topography, patchy coral reefs and seagrass beds) but PS is an island adjacent to the coastline, which is not the case for PPP. As there are no restrictions and law enforcement, the consequences of fish bombing and biodiversity depletions are more visible in the waters around those two sampling areas. Except the TARP, where I was going daily, all the samples on the other islands were during field trip sessions, either for day trips or longer stays (5 days in a row for PTMP and 4 days for PPP). The sessions were planned before for logistic issues, even if we could have dived more during our stays on the islands.

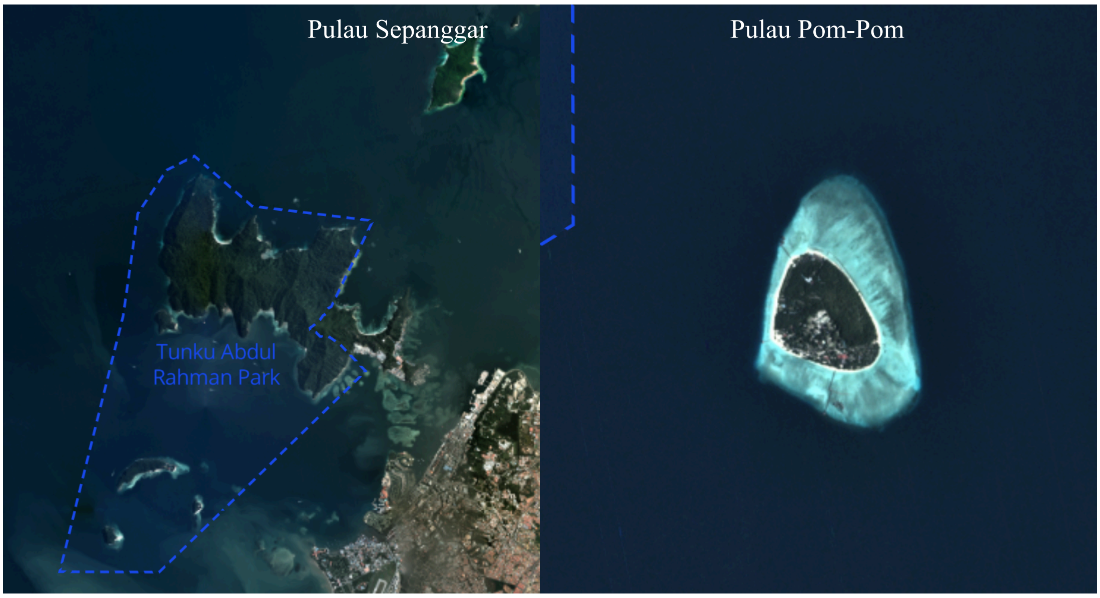


Figure 2.4 and 2.5 : Screenshot of Pulau Seppangar (left) and Pulau Pom-Pom, from a coral reef atlas (https://allencoralatlas.org/). We can see that both islands are close to protected waters (delimited in blue), respectively the TARP for Pulau Sepanggar and the Tun Sakaran Marine Park for Pulau Pom-Pom.

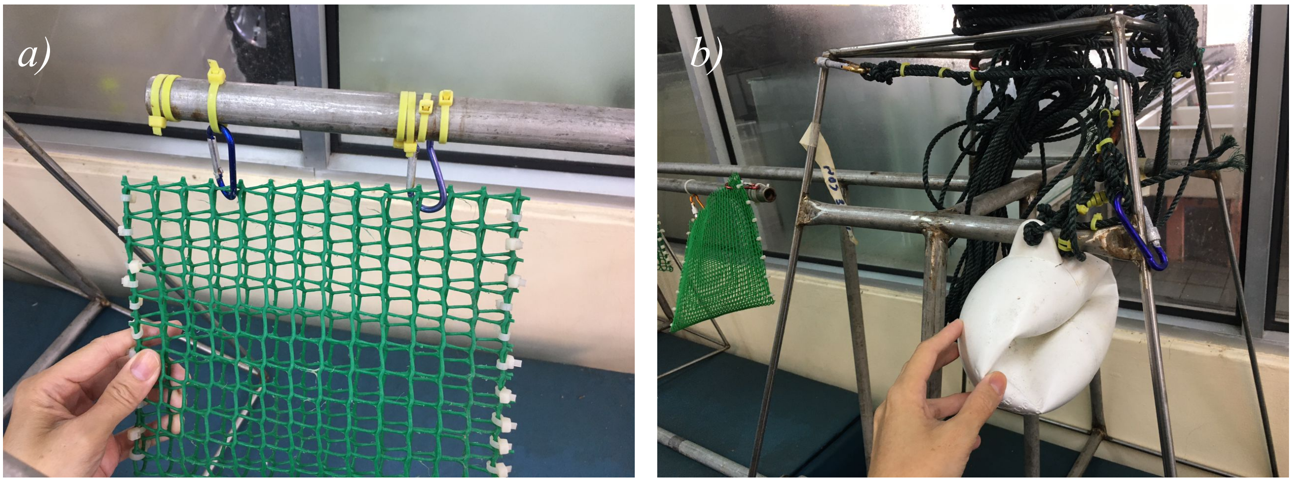
2.2 Sampling material

The aim of the study is to assess elasmobranch diversity and relative abundance in all the different aquatic habitats of the marine parks and non-protected waters nearby. The surveys need to be standardized replications of the methodology, at any depth and covering all the environments (Brooks et al., 2011). They require to be randomized, stratified transects to cover the biggest surface underwater. Assessing the state of elasmobranchs will allow us to understand the factors influencing their abundance, distribution and the conservation issues (McCauley et al., 2012 ; White et al., 2013).

Baited Remote Underwater Video Systems (BRUVS)

Baited Remote Underwater Videos Systems (BRUVS, Figure 7) were used to record 1 hour movies at the sampling locations, during daytime (McCauley et al., 2012). A square - basis metal structure held the camera calibrated on 720p (Action Cam NK Explorer 10), with an arm holding the bait in a mesh bag at 1,5m in front of the camera. The bait is usually composed of a mixture of local, oily fish selected from the local markets (*Decapterus* spp.). A buoy is placed at the top of the structure to keep the buoyancy while sinking, and is attached to a rope system and another buoy at the surface to localize it faster (Figure 2.6).

Figure 2.6 : Pictures of the BRUVS structures present at the BMRI, with details on a) the mesh bait bag clipped to the end of the steel arm, and b) the buoy and rope system to maintain the structure straight while sinking.



Underwater Visual Census (UVC)

Elasmobranch abundances and specific richness have also been measured while scuba diving, using a *GoPro Hero 7 Black Edition*, which was not impacted by the water's turbidity or the movements while swimming (Brooks et al., 2011). No bait was used to attract the elasmobranch for this method, and the majority of the dives were undertaken during daytime (only 2 night dives). A minimum of two divers were doing the transects, to be more focus on the biodiversity and for safety reasons.

2.3 Sampling methodology

Baited Remote Underwater Video Systems (BRUVS)

The BRUVS were deployed from the boat on the sampling sites, and separated by at least 200-300 meters from the diving sites, to avoid elasmobranch individuals to forage the baits and being on the records from the scuba-diving census (Langlois et al., 2010 ; Willis et al., 2000). The baits were bought the morning before the field session, to maintain them fresh, and the mixture was prepared on the boat.

Underwater Visual Census (UVC)

As it is particularly difficult to assess elasmobranchs while setting up a transect belt (they would flee the divers), we decided to use a standardized methodology (McCauley et al., 2012). The divers recorded during 3 minutes, which corresponds to a 50 meters distance, following a linear direction and staying at the same depth. This is a similar method to the transect belt method used in different studies (Willis et al., 2000 ; McCauley et al., 2012 ; Langlois et al., 2018), where the divers follow a belt transect and assess the elasmobranch individuals coming. The divers were swimming really slowly - just above the bottom (less than 1m per second). A gap of at least 20 meters or few minutes swimming was undertook before starting another transect record, to reduce disturbance due to the diver's presence (Langlois et al., 2010 ; Colton & Swearer, 2010). For each transect, spotted species and the bottom coverage (percentage of coral reefs, sand, rock and rubles) were recorded on an underwater slate.

2.4 Statistical analysis

For the statistical analysis, the software R/RStudio (version 4.2.0, package *ade4*) was used to plot all the results (https://www.rstudio.com/products/rstudio/). Two box plots were created showing both abundance and specific richness, divided in location group (3 groups : TARP, Other MPAs and Outside waters). The box plot were made by depth : either shallow waters from 0 to 12m depth and deep-water from 12m to 36m depth (the deepest transect). A Kruskal-Wallis test (also called one-way ANOVA on ranks) was made to evaluate if the different sample groups were originated from the same distribution and to test the significance of the differences. For significant results ($p < 0.05$), Dunn's test was used for pairwise comparisons. Moreover, to analyze the data collected, a PCA (Principal Component Analysis) and a multiple FCA (Factorial Correspondence Analysis) were carried out.

The correlation circles (PCA) allow us to project variables on a X-Y axis and perceive which factors are linked and which ones are impacting the variables we are working on. Here, we want to see if the visibility, the temperature, the transect depths and the proportion of coral reefs are positively or negatively correlated to the elasmobranchs sights, thus both abundance and specific richness.

The FCA is a statistical method used to investigate the link in between two qualitative variables. It creates a multidimensional representation (on a X-Y graph) that helps to figure out the proximity between variables and observations. For our study, we evaluated for each specie their relationship, either strong or soft, found in our 3 sampling groups : the TARP, the Others MPAs and the Outside waters (non-protected).

3. RESULTS

3.1. General results

A total of 17h was recorded by the BRUVS in three of the stated locations : in the TARP, Pulau Tiga Marine Park (PTMP) and Pulau Sepanggar (PS). The footage were recorded between the 8th of June 2022 and the 7th of July 2022, during daytime (earliest was at 9:15AM and latest at 2:55PM), from 3 to 18m depth. Only 3 individuals were sighted during this amount of time (one *Taeniurops meyeni* in PTMP, one *Carcharhinus melanopterus* and one *Mobula thurstoni* in PS), and for this reason, we decided that the BRUVS were inefficient for our study. Thus, we focused our sampling methodology on the UVC.

From the 2nd of June 2022 until the 10th of August 2022, a total of 48 dives and 266 transects, ranging from 3m depth to 36m depth were conducted, mostly during daytime (earliest was at 6:55AM and latest at 8:50PM). We dived twice during night time in the TARP, and it was the only place where we could do it, due to logistic and administrative issues. We undertook 26 dives and 129 transects within the TARP. For the other MPAs, we undertook 5 dives in the PTMP and 3 in the Pulau Sipadan Marine Park (PSMP), with respectively 26 and 23 transects. About the non-MPA areas, 9 dives and 58 transects were conducted at PS, and at Pulau Pom-Pom (PPP) 5 dives and 30 transects were conducted.

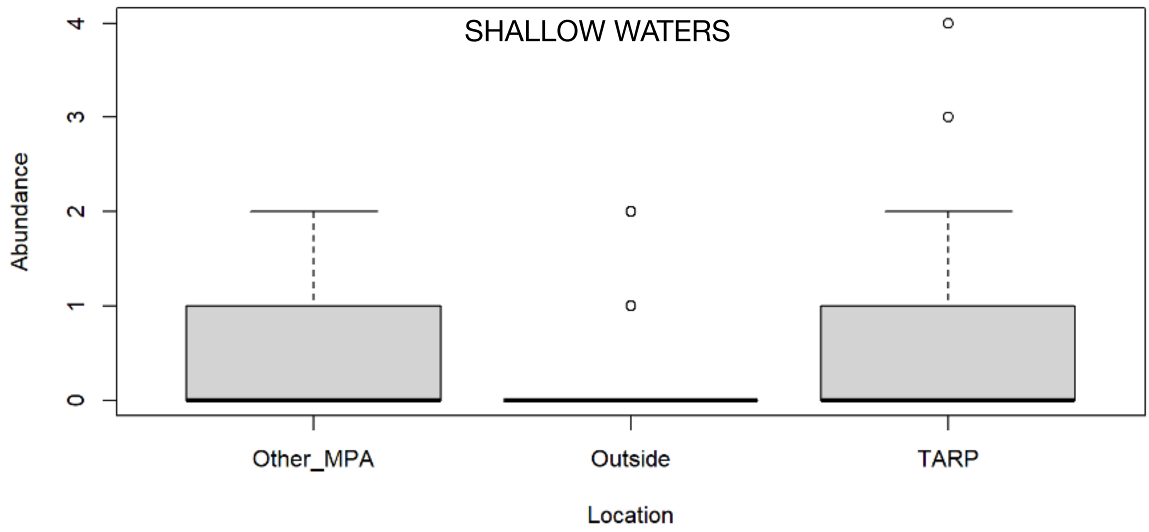
We spotted a total of 86 elasmobranch individuals from 8 species (5 of sharks and 3 of rays) (Table 3.1). The rays comprised 69.7% (n = 60) of the sightings and the sharks 30.3% (n = 26). Two species of blue-spotted rays (*Taeniura lymma*, n = 41, 47.7% and *Neotrygon orientalis*, n = 17, 19.8%) appeared as the most dominant species. The most abundant species of shark is *Carcharhinus melanopterus*, with 11 individuals spotted. It should be noted that 3 other species of sharks were found only in one particular location : *Chiloscyllium punctatum* was only sighted in PTMP, *Triaenodon obesus* and *Carcharhinus amblyrhynchos* were only sighted in PSMP. MPAs were the locations where most of the elasmobranchs were found (n = 73 individuals, respectively 49 in the TARP, 15 in PSMP and 9 in PTMP). Only 13 elasmobranchs were spotted in the non-MPA areas, 8 individuals in PPP and 5 individuals in PS. The TARP appears to be the place with the highest elasmobranch abundance (n = 49, 9 shark individuals and 40 ray individuals) and specific richness (5 different species, PSMP, PTMP, SP possess 3 different species and PPP only 2).

Table 3.1 : Summary of all the elasmobranchs sighted, ranked by species and locations. The first 3 species are rays (Taeniura lymma, Neotrygon orientalis and Aetobatus ocellatus) and the rest are different species of sharks.

Species	TARP	PTMP	PSMP	PS	PPP	Total
Taeniura lymma	26	6	0	2	7	41
Neotrygon orientalis	13	2	0	2	0	17
Aetobatus ocellatus	1	0	0	0	1	2
Atelomycterus marmoratus	2	0	0	1	0	3
Carcharhinus melanopterus	7	0	4	0	0	11
Carcharhinus amblyrhynchos	0	0	4	0	0	4
Triaenodon obesus	0	0	7	0	0	7
Chiloscyllium punctatum	0	1	0	0	0	1
Total	49	9	15	5	8	86

3.2. Box-plot results

A total of four different box-plots were created for this study. We evaluated the abundance and the specific richness of the elasmobranchs sighted, with a depth-condition. Each variable was divided in two categories : the shallow waters, where the transects were lower than 12m depth, and the deep waters, where the transects were deeper than 12m depth. Moreover, we analyzed the abundance and specific richness distribution with a focus on the different dive sites. We split the data in 3 main groups : the TARP, our MPA of focus, the other MPAs where we sampled (PTMP and PSMP, respectively the group called "Other_MPA") and the non-protected areas nearby those MPAs (PS and PPP, respectively the group called "Outside").



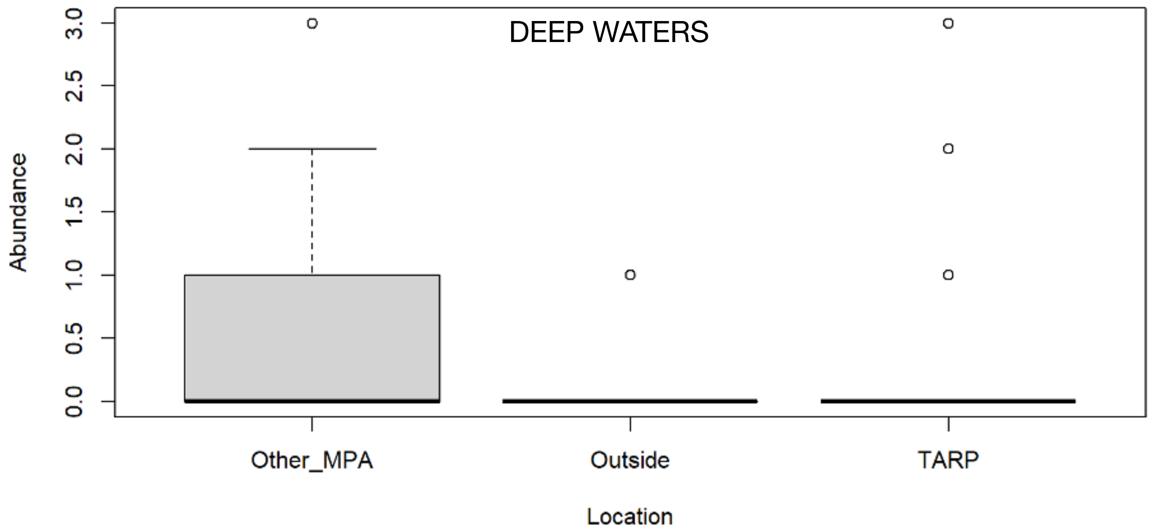


Figure 3.2 : Box-plots showing the abundance of elasmobranchs in function of the sampling areas type : the TARP, the other MPAs and the non-protected waters (Outside). The upper box-plot is showing the abundance in the shallow water transects (<12m depth) while the lower one is for the deep water transects (>12m depth, maximum 36m).

From the box-plot of the shallow waters (Figure 3.2, upper box-plot), we can see that all the protected areas ("Other_MPA" and "TARP") possess a higher abundance than the unprotected areas ("Outside"). The TARP got extreme values higher than the other MPAs, but the shape of their respective box-plot are similar. Nonetheless, these results are not statistically significant, as we can see from the results of the Kruskal-Wallis test (n = 44, Kruskal-Wallis test = 4.1721, df = 2, p-value = 0.1242).

The box-plot for the deep water transects (Figure 3.2, lower plot) is showing that the other MPAs got a higher abundance than the unprotected waters and the TARP, which are null. All of the box-plots possess extreme values, as we spotted elasmobranch individuals everywhere, but in a fewer amount. In addition, those results are statistically significant, as shown by the Kruskal-Wallis test results (n = 42, Kruskal-Wallis test = 6.9956, df = 2, p-value = 0.0303).

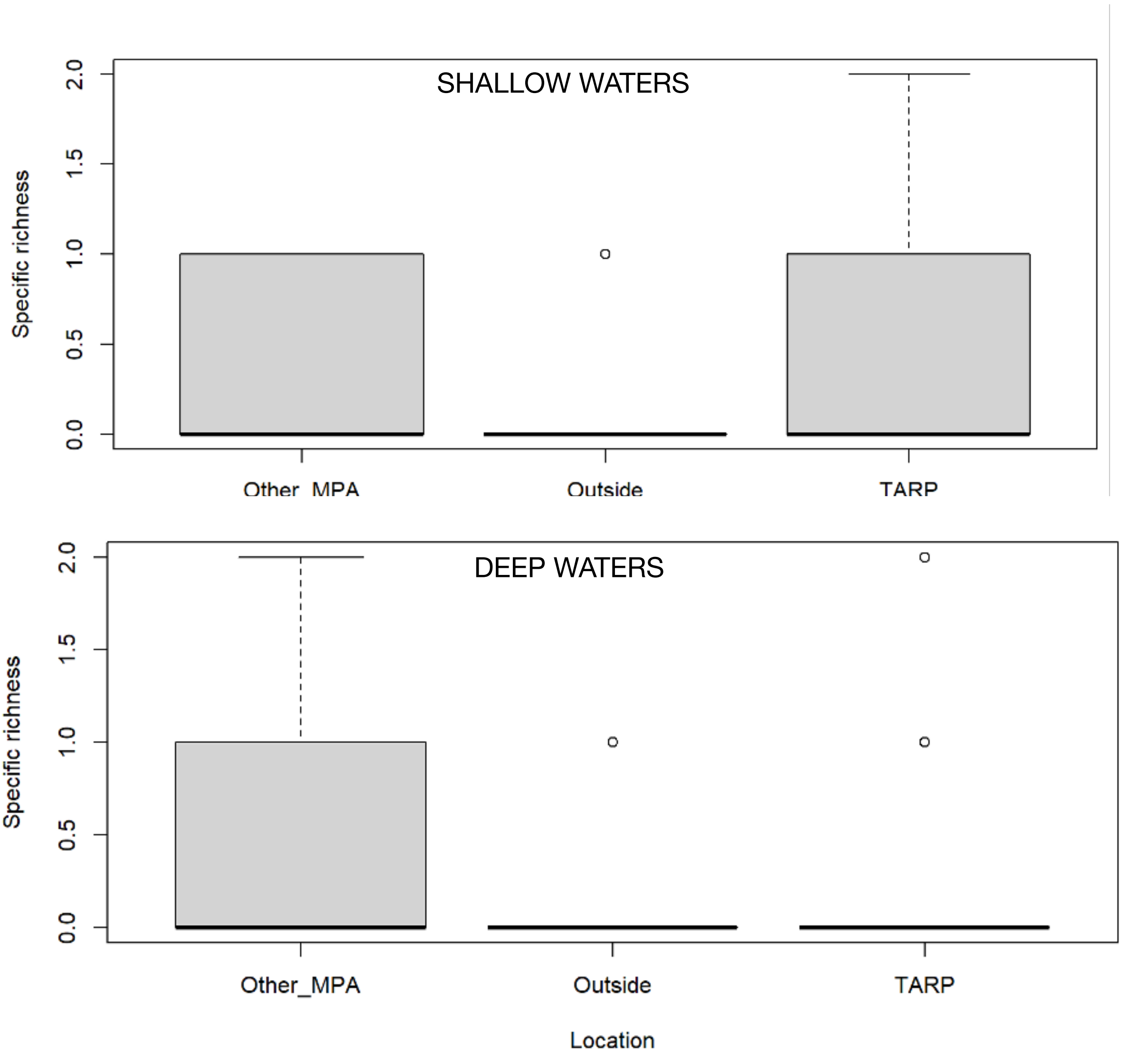


Figure 3.3 : Box-plots showing the specific richness of elasmobranchs in function of the sampling areas type : the TARP, the other MPAs and the non protected waters (Outside). The upper box-plot is showing the specific richness in the shallow water transects (<12m depth) while the lower one is for the deep water transects (>12m depth, maximum 36m).

To understand which pair were significantly different, a Wilcoxon paired test has been conducted. It reveals that the TARP was significantly different from the "Outside" (w = 968, p-value = 0.0028). In another hand, the data being lower than 15 sights, the "Other_MPA" group cannot be tested and compared with the other groups.

The results for the specific richness are more or less the same as those for the abundance. In the shallow waters (Figure 3.3, upper figure), the protected areas has the same amount of specific richness compared to the unprotected ones. Also, it is again in the TARP where we noticed the highest specific richness. But those results are not statistically significant, as shown by the results of the Kruskal-Wallis test (n = 44, Kruskal-Wallis test = 4,0586, df = 2, p-value = 0,1314). For the specific richness in deep waters, it is again in the other MPAs where it is the highest (Figure 3.3, lower box-plot). Like for the abundance, the statistical test is significant (n = 42, Kruskal-Wallis test = 6,9552, df = 2, p-value = 0,0309) and a Wilcoxon paired test has been conducted to understand which pair is significantly different. It reveals that the TARP was significantly different from the "Outside" (w = 960, p-value = 0.0022). For the same reasons as the abundance, (stats being lower than 15 sights), the "Other_MPA" group cannot be tested and compared with the other groups.

3.3. Principal Component Analysis (PCA) results

With all the sightings (n = 86), without the 3 individuals spotted by the BRUVS, we performed 2 PCAs to analyze the abundance and specific richness of the elasmobranchs. A few parameters were tested to evaluate their effect on both variables. The visibility was, obviously, the most important factor for the abundance and the specific richness. If the water is murky or full of particles, the divers cannot spot all the individuals, thus the real abundance and specific richness. For this reason, when monsoons occurred, we did not go sampling. First because it was dangerous to take out the boat with those weather conditions, then because the visibility was really bad (usually less than 5m). The same issue happens also for the BRUVS, even thought they were not included in the data. The proportion of coral reefs is the second most important factor. On both graphs (Figure 3.4 and 3.5), we can see that the factor "Coral reefs" is within the same quarter as the tested variables. Elasmobranchs individuals were more spotted more frequently on a coral reef bottom than any other type of substrate (sand or rubbles). On the second PCA, we did not include those two other bottom surfaces in order to keep the graphs clear. As the individuals are seen either on coral reefs, sand or rubbles, adding two more parameters is pointless, especially because they will be at the opposite of the coral reefs.

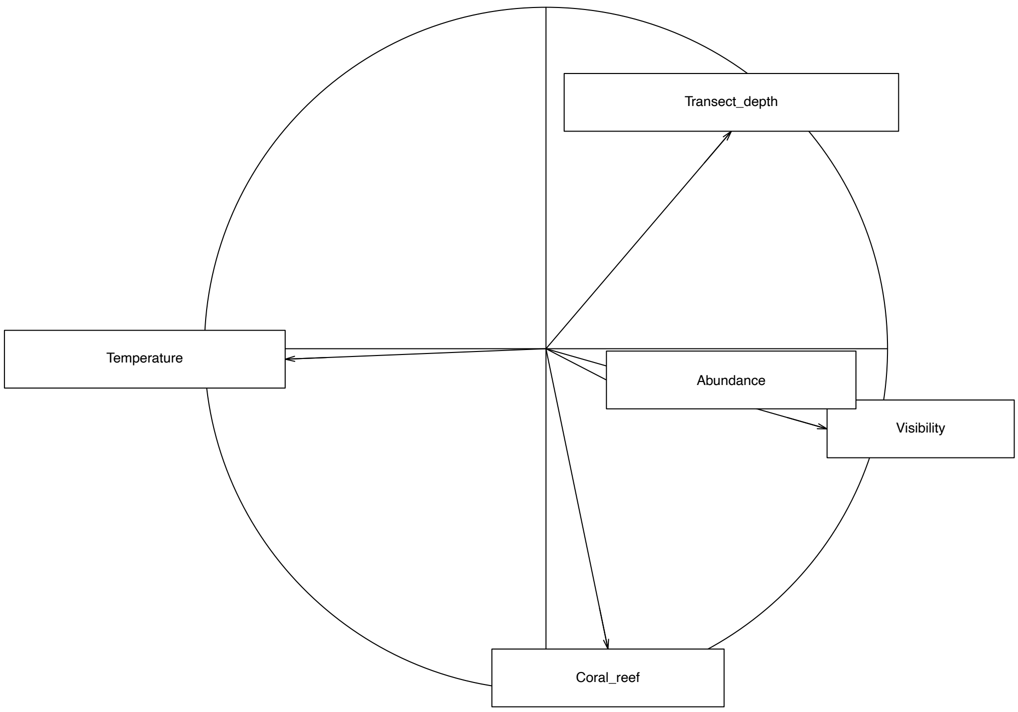


Figure 3.4 : Correlation circles (or PCA) of the elasmobranch abundance in the State of Sabah. The most important variables are the closest ones, or the ones in the same quarter. For example, the temperature here is not inducing any effect on the abundance.

Therefore, we can assume their positions on the graphs with only the “Coral reefs” factor. Furthermore, the transect depth does not influence the abundance or the specific richness much. We can assume that being in tropical waters the depth is only changing the bottom surface. Light is quite present, especially since the transects were most of the time not that deep (36m the deepest, and only on one occasion). Thus, neither the visibility nor the coral reefs were affected by depth, and the same scheme goes for the elasmobranch individuals. Finally, we can easily see that the temperature is at the opposite side of our tested variables. This factor has no effect on the sightings, the water temperature usually being the same everywhere and at any depth, ranging from 29 to 32°C depending on the different dive sites.

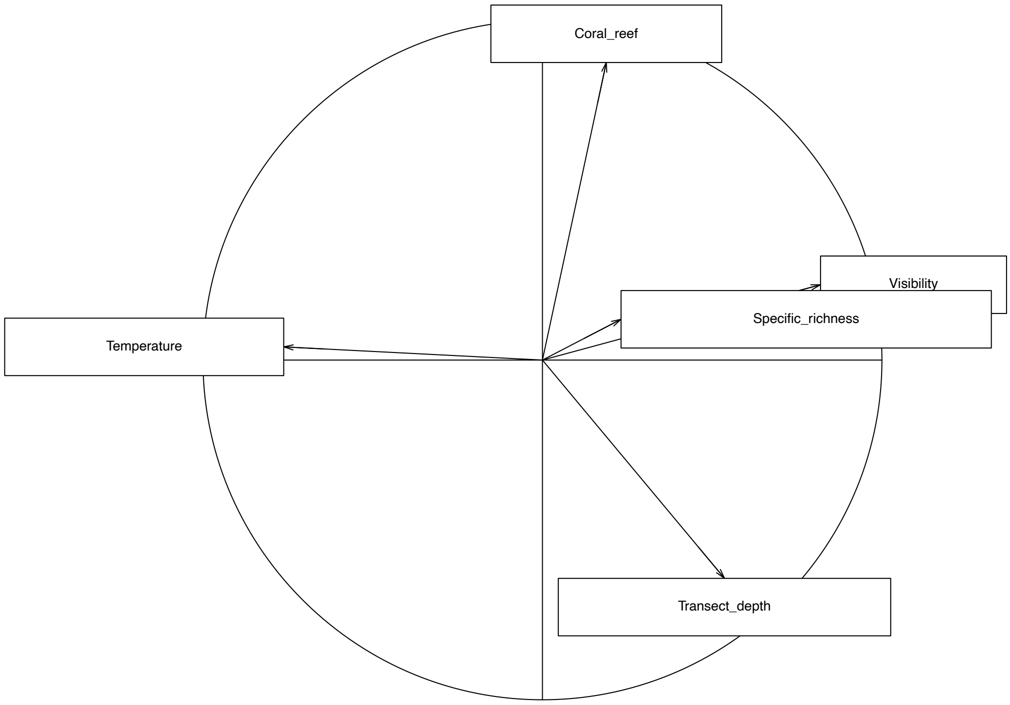


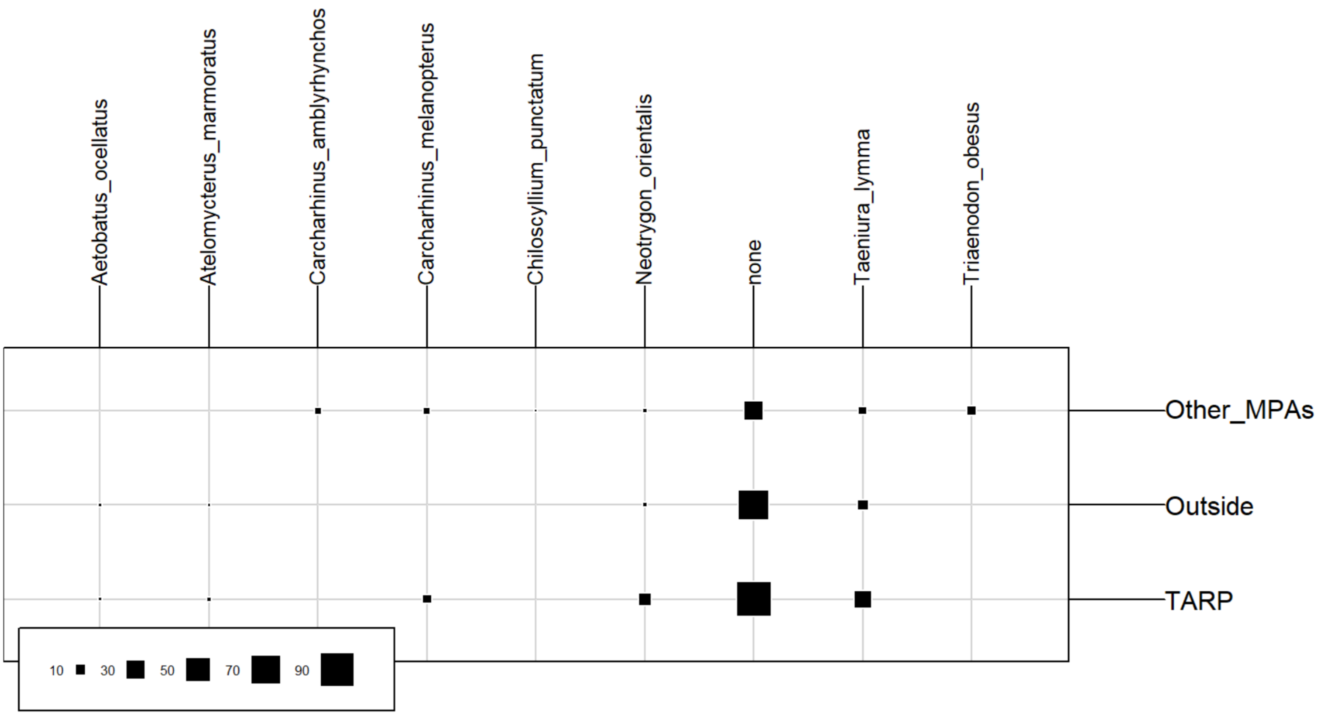
Figure 3.5 : Correlation circles (or PCA) of the elasmobranch specific richness in the State of Sabah. The most important variables are the closest ones, or the ones in the same quarter. For example, the temperature here is not inducing any effect on the abundance.

We also wanted to analyze the temporal effect on both variables, but our data was not relevant enough to incorporate it in the study. We were not able to write down the exact time when an individual was spotted underwater. We only have the starting and ending time of the sampling dives, which is not relevant. In addition, an interesting parameter to determine would have been the diurnal-nocturnal proportion of elasmobranchs, but again we only were able to dive during the night time for a few times and only in the TARP.

3.4. Factorial Correspondence Analysis (FCA) results

The FCA table (Table 3.6) shows where a species was observed the most as a function of the three different location groups. We can see, as in the results for the abundance and the specific richness, that there was a huge number of transects where we did not see any elasmobranchs. This outcome is represented by the big squares for the column "none". For the two species of blue spotted rays (*Taeniura lymma* and *Neotrygon orientalis*), the two dominant elasmobranch species of the study, the TARP is the sampling site where we saw them the most. Also, they are the two only species found in the three different groups, showing their widespread distribution within the Sabahan waters. As in the Table 3.1, some species of sharks are associated with only one location group (*Carcharhinus amblyrhynchos*, *Chiloscyllium punctatum*, *Triaenodon obesus*). We can highlight here that they were found in other MPAs than the TARP, but not in unprotected waters.

Table 3.6 : Factorial Correspondence Analysis table. For all the species sighted during this study, this table shows the locations where they were most seen. The bigger the square is, the more individuals we saw.



Furthermore, the group "Other_MPAs" possesses the highest specific richness, with almost all the species of the study sighted within the borders of these 2 MPAs (PTMP and PSMP). The black tip reef shark (*Carcharhinus melanopterus*), most common shark specie of the study, was also seen only in MPAs, either "TARP" or "Other_MPAs" (even though a single individual was also sighted with BRUVS in PS, an "Outside" location). All of the last outcomes are another proof showing the importance of the MPAs in term of elasmobranch conservation. About the elasmobranch abundance, the TARP is the location where a majority of the individuals were observed, but this is logical as the number of dives (therefore transects and sightings) is greater than anywhere else. To finish with this table, we can clearly notice the gap in between the MPAs and the unprotected waters (« Outside »), where only a few individuals were spotted. Those waters possess the lowest specific richness and abundance of the three different location groups.

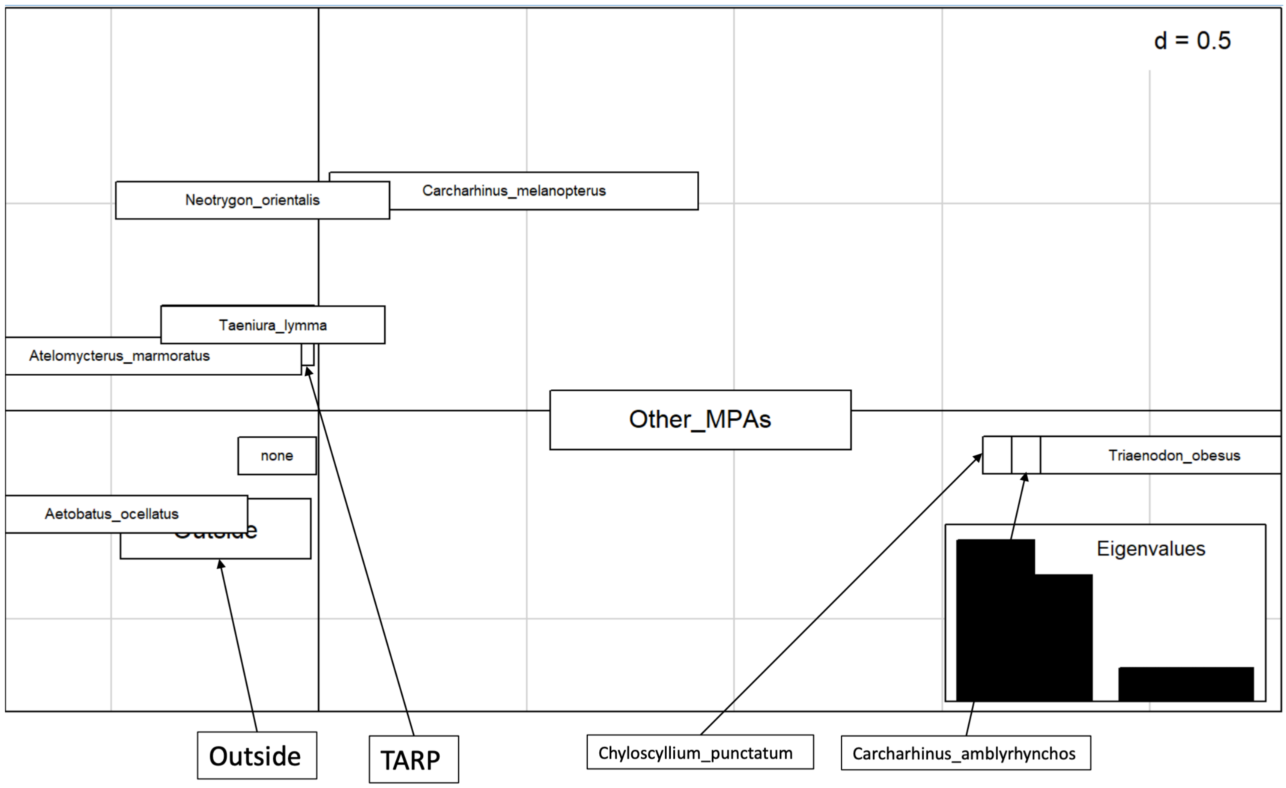


Figure 3.7 : Factorial Correspondence Analysis X-Y graph. This graph also shows the affinity between the locations and the species. The closest the specie is from a location group, the more individuals we sighted during transects in those locations.

With regard the FCA X-Y graph (Figure 3.7), the three location groups are situated at different places on the graph ("TARP" is hidden behind the specie *Atelomycterus marmoratus* and "Outside" behind *Aetobatus ocellatus*). The distance between the location groups and the species represents their affinity : the closest the species is to the location, the most sights of it we recorded within the waters of this location. We can see that a few species are really correlated with particular places : the coral cat shark (*Atelomycterus marmoratus*) and the blue spotted ribbon tail ray (*Taeniura lymma*) are strongly correlated with the TARP, the same goes for the ocellated eagle ray (*Aetobatus ocellatus*) with the "Outside" waters and the species of sharks found only in the other MPAs, as said previously, are all close to the "Other_MPAs" box. The species in between two locations, like the black tip reef shark (*Carcharhinus melanopterus*) and the blue spotted stingray (*Neotrygon orientalis*) are, logically, found in both places. Basically, this graph is stating the same outcomes as the FCA table (Table 3.6), but with the data put on a 2-D scale, to have a better perception of the outcomes found.

4. DISCUSSION

4.1. Abundance and specific richness in Sabahan waters

From the box-plots made with the software R/RStudio (Figure 3.1 and 3.2) and the FCA table (Table 3.6), we can conclude that the elasmobranch abundances are low, both in protected and non-protected Malaysian waters. The FCA table demonstrates that a large number of our samples were without any elasmobranch sightings. It is even more obvious for the deep water transects, where both unprotected waters and the TARP waters possess a null median. It is however logical, as we were diving and focusing on the elasmobranch reef communities. The UVC methodology does not allow us to go too deep, and the dive sites surveyed too. The proportions are still higher in the MPAs, which highlights of their role in the well-being of the elasmobranch populations (Martín et al., 2020 ; McCauley et al., 2012). Yet, compared to other tropical places around the world, these features still remain poor (MacNeil et al., 2020).

When we focus on the TARP, we notice that the mean abundance is equal to other MPAs (PTMP and PSMP) in shallow waters, but not in the deep waters. This can be explained by the fact that the dives in PSMP were deeper than anywhere else, due to the particular oceanic position of the island (3 dives, with for maximal depth of 29m, 33m and 36m while within the TARP it was difficult and pointless to go below 25m depth). Of the 15 elasmobranchs sighted in the PSMP, only one was in shallow waters (depth = 8m), while most individuals were seen below 20m depth. Thus, even if the number of transects is bigger in the TARP than the other MPAs, more individuals were seen in the deep waters of other MPAs. However, the total amount of individuals sighted is higher in the TARP than the two other MPAs, as we undertook more transects within the TARP boundaries. The results of the analysis of the abundance in the unprotected waters compared to the TARP is following what we were expecting. As expected, the elasmobranch biodiversity is suffering in non-protected areas, due to overexploitation (Shah et al., 2016). The results validate this supposition, showing a low abundance in the unprotected waters. Therefore, the TARP has higher abundances than the outside waters, at every depth.

The analysis of the specific richness is following the same trends as the abundance : the specific richness is higher in protected areas (both « Other_MPA » and « TARP »), equal between the

TARP and the « Other_MPA » in shallow waters but not in deep waters. Again, due to the oceanic remote position of Pulau Sipadan (PSMP), some pelagic elasmobranch species were only found while diving there in our study, which increased the specific richness at deeper depths (the white tip shark *Triaenodon obesus*, the grey reef shark *Carcharhinus amblyrhynchos*). Moreover, when comparing the specific richness of both TARP and unprotected waters, the results are explicit : the TARP is richer than the unprotected areas, both in shallow and deep waters, with the FCA results highlighting all those outcomes : the TARP possesses five different elasmobranch species, the outside waters four species and the two other MPAs counted six species within their boundaries.

With regard the two dominant species, the two species of blue-spotted rays *Taeniura lymma* and *Neotrygon orientalis*, our results corroborate previous studies in TARP and other MPAs in Sabah (Mopilin & Manjaji- Matsumoto, 2019 ; MacNeil et al., 2020). This MPA was the location where found the highest abundances (again because of an higher amount of transects), but they still remained the two most widespread and abundant species in the Sabahan waters. Some supposedly widespread species, like the ocellated eagle ray *Aetobatus ocellatus*, were only found a few times, with minimal contributions to the abundance and specific richness of the surveyed areas. The brown banded-bamboo shark (*Chiloscyllium punctatum*), supposedly common and widespread in the Sabahan waters, was also only found in the PTMP (« Other_MPA »), even if it should be present in the TARP waters (Townsend, 2015). Since the Sabah Parks Headquarters, based on Pulau Manukan, possess an individual in their aquariums caught within the boundaries of the MPA.

Thus, our MPA of focus, the TARP, has higher abundances than anywhere else we surveyed, mostly because the number of transects are not the same. When we compare the elasmobranch individuals sighted, it appears that the TARP has lower elasmobranch abundances in the deep waters than the two other MPAs, but higher abundances in general compared to unprotected waters. Those outcomes are in agreement with previous studies, showing the importance of MPAs and shark sanctuaries for the well-being of their conservation (Albano et al., 2021 ; Assad et al., 2018 ; Bünfil, 1997). In the Goetze & Fullwood (2013) article, one of the major outputs is that the biomass and abundance of elasmobranchs were significantly greater within the boundaries of MPAs compared to outside (2x greater at shallow waters and 4x greater in deep waters).

4.2. Correlations between influencing factors and sightings

As stated in the results part, the « coral reefs » were the bottom surface where most of the elasmobranchs were sighted. Indeed, most of the individuals sighted are demersal species, and spend a huge amount of their lifetime close by (Ellis et al., 2005). This is the case for the coral cat shark (*Atelomycterus marmoratus*), the brown banded bamboo shark (*Chiloscyllium punctatum*), the two species of blue-spotted rays (*Taeniura lymma* and *Neotrygon orientalis*), that can stay hidden for hours under coral reefs or rock formations until the night time, where they are more active and forage epibenthic preys (Espinoza et al., 2015). For the other more pelagic species, they are less influenced by the proportion of coral reefs as their home range size are greater (*Knip et al., 2010 ; Dulvy et al., 2017*). Yet, all the other species listed (the blacktip reef shark *Carcharhinus melanopterus*, the white tip shark *Triaenodon obesus*, the grey reef shark *Carcharhinus amblyrhynchos* and the ocellated eagle ray *Aetobatus ocellatus*), even if they are not as dependent as the other species, still spend a big part of their lifetime around coral reefs, to aggregate, forage, and reproduce (Ali et al., 2018 ; Heupel et al., 2010 ; Speed et al., 2016). Therefore, it seems coherent that coral reefs are more linked to the abundance and specific richness on the PCAs than any other bottom surface. These assumptions made from the PCA are in a way logical : we need healthy coral reefs in our oceans to keep a certain amount of biodiversity in the ecosystems (Allen, 2008 ; Veron et al., 2011).

However, the sandy bottoms were a playground for some ray individuals, being demersal species, in particular with the two species of blue-spotted rays *Taeniura lymma* and *Neotrygon orientalis* (personal observations, Sherman et al., 2018). Most of the sightings of those two species were on the sand or on coral reefs, but not much on the rubble bottoms. The same outcome goes for the only individual of Blotched Fantail stingray (*Taeniurops meyeni*), spotted with the use of BRUVS on sandy bottom (Figure 4.3). Basically, rubble formations are induced by dynamite fishing, a method where local people fish with dynamite. Those destroyed environments are not shelters for any kind of biodiversity, and that is why very few elasmobranch individuals were sighted on them. The only individuals sighted on rubble possessed a « traveling behavior » and were not foraging or aggregating.

The correlation between the visibility and the number of sights is also quite logical. The greater the visibility is, the higher chance the diver has to spot an elasmobranch. The PCA graphs are indeed representing this outcome, where both abundance and specific richness are really adjacent to the visibility. It seems accurate to claim that the abundance and the specific richness are more linked to the visibility than any other factors.

The correlation between the depth and those two variables is also not surprising. For each species, we have sighted individuals in both shallow and deep waters. It looks then normal that this factor is less influencing the recorded data, and thus the abundance and specific richness, than the two previous factors mentioned previously. From the box-plots, the abundance and the specific richness are higher in the shallow waters than the deep ones. Being in a tropical ecosystem, most of the biodiversity is accumulated within depths of the first meters. For that, there is more chance for elasmobranchs to forage in shallow waters than in deep waters. The lifestyle of several species of this study, such as the black tip reef shark, is also more suited for shallower environments (Osgood et al., 2015). However, this information needs to be confirmed, as the statistical results showed a significance for only the deep water abundance and specific richness. Finally, we can see easily that the temperature is at the opposite of our tested variables. This factor has no effect on the sightings, the water temperature usually being the same everywhere and at any depth, ranging ±29-32°C depending on the different dive sites. Most of the elasmobranch species of the study are used to these temperatures, and again, being in a tropical area, the average temperature does not change a lot during the year.

4.3. Methodology bias

Spatial and temporal issues

There is a spatial and temporal scale that we need to take into account (Langlois et al., 2010). Most of the records were made during daytime, as the light was not letting us perform our tasks properly during night time. But it is well known that most elasmobranchs forage during early morning and the night (Last et al., 2010 ; Hammerschlag et al., 2017).

Some species are known to be present in the Sabahan waters, but due to a short field trip period and logistic issues, not all of them were found. For example, it is apparently common to dive with whale sharks (*Rhincodon typus*) in between January and March, probably because the TARP is on their migration path (Townsend, 2015). In the same article of Townsend (2015), report that zebra sharks (*Stegostoma fasciatum*) and pink whip rays (*Himantura fai*) were also found in the TARP, which was not our case. Those observations occurred on a bigger time scale, which increase the probability to sight elasmobranch species. Moreover, certain species might adopt philopatric behavioral patterns and stay outside the borders of the MPA during the day but can come back during the night to forage or mate (or the opposite pattern) (White et al., 2013 ; Osgood et al., 2019). Zebra sharks are known to be seasonal and potentially my stay in Borneo did not match with their aggregations inside the TARP (Dudgeon et al., 2008 ; Townsend, 2015). Same spatial distribution can happen with depth, going deeper during the day and then going towards the surface or inside lagoons to hunt. Therefore, the possibility to not assess the whole diversity became real.

We found only a few coral cat sharks (*Atelomycterus marmoratus*) within the borders of the TARP, and no bamboo shark species at all (*Chiloscyllium punctatum*, *Chiloscyllium plagiosum*), which again was the case for Townsend (2015). All those species are known to be present on all the sampling sites, but our results do not correlate with those assumptions. This might be due to the nocturnal behavior of those species, that stay most of the time hidden during day time and go out when the sun sets to forage, mate or just aggregate (Hammerschlag et al., 2017 ; Whitney et al., 2007). For this study, it was quite complicated to sample during night time. The Sabah Parks authorities did not allow us to use the boat during the night, so the only way to perform late samples was to stay overnight on Pulau Manukan (TARP) and dive from the beach. In addition, none of the other sampling locations allowed us to sample during night time, especially when the field trip sessions were only for day trips (like for example Pulau Sipadan). Therefore, it was challenging to assess the whole specific richness of the different study sites on a full temporal scale, knowing that we could only assess during day time.

Another spatial issue is the size of the surveyed areas : the larger the sampling area is, the more chance you will have to sight and discover new species. This works especially for MPAs and large predators such as elasmobranchs, which can potentially migrate outside the MPAs (Espinoza et al., 2016). Ideally, for this study, a greater number of dives in the study areas and a few more study areas would have resulted in much more consistent data, with probably a higher elasmobranch specific richness in the Sabahan waters. In our study, the MPAs surveyed were not part of the biggest ones in the State of Sabah (the TARP encompasses only 50 km², PTMP encompasses 158 km² and PSMP is covering a no-take area of 168 km²). In comparison, the Tun Mustapha Marine Park, up north Borneo island, is covering almost 9000 km² and more than 50 islands (https://www.sabahparks.org.my/tun-mustapha-park). This type of MPA is more suited for large migratory pelagic species, as it can protect all the different life stage of the species (Claudet et al., 2008 ; Bünfil, 1997). According to the article of Speed et al. (2015), the size of the surveyed MPAs of this study could benefit the juvenile elasmobranchs but is limiting for the adult individuals. As their home range size are bigger than those of juveniles, the MPA cannot encompass the total surface. In addition, small MPAs do not allow the assessment of the true specific richness and abundance of the elasmobranch populations and tends to underestimate them (Claudet et al., 2008). Finally, the survey size is more precise when the data pool is bigger (McCauley et al., 2012). Logically, for abundance and specific richness analysis, the more individuals you sight, the more consistent the data pools will be.

UVC issues and bias

Both methods are weather dependent : for both diving and underwater records, if there is turbidity (due to run-offs, currents or monsoons) the accuracy of the surveys will decrease (Willis et al., 2000 ; White et al., 2013). Current circulation can also disturb the survey process as a drift dive can be more complex (White et al., 2013), which was the case for our scuba-diving census in PSMP. Performing surveys while diving can alter the behavior and the density estimations of the elasmobranchs present in the area (Willis et al., 2000 ; White et al., 2013 ; McCauley et al., 2012). Some individuals will be curious and attracted by the divers, and some can be the opposite and leave the area (McCauley et al., 2012). This might imply some bias if the divers did not count them yet, and a « game » of attraction and avoidance can be set. According to the article of Bradley et al. (2017), the divers are not inducing behavioral changes while diving with reef sharks. But the mobility of the elasmobranchs should also be taken into account while surveying them, as they sense or detect the divers earlier than the divers can them (White et al., 2013). Thus, it is important to consider the life history and the biogeographic patterns of the target species before going to survey some dive sites (White et al., 2013).

Another issue while conducting UVC is the limit of depth, time and air. Basically, UVC surveys require much more in term of logistics than just throwing a BRUV structure underwater. First, it is time consuming compared to the BRUVS (preparation, travel, dive in itself, analysis and writing of the outputs) and you cannot stay underwater for an unlimited time due to pressure, depth and air limits (Langlois et al., 2010). Then, for safety reason, you must always find a diving buddy, which sometimes cannot happen and postpone the potential field session.

According to Colton & Swearer (2010), even if undertaking UVC surveys possesses the mobility advantage compare to BRUVS, they still recommend the use of BRUVS. UVC surveys allow the divers to pass through different elasmobranch territories and sight them in complicated cryptic areas, but there is still a probability to underestimate the elasmobranch populations (Willis & Babcock, 2000).

4.4. Inefficiency of the BRUVS during the study

Another bias in our methodology was the use of BRUVS. From different studies, a BRUVS-study conducted on elasmobranchs got different specific richness, with one or two dominant species (Goetze & Fullwood, 2013). According to Sherman et al. (2018) article, we were thus expecting the blue-spotted rays (*Taeniura lymma* and *Neotrygon orientalis*) to dominate the abundance of elasmobranchs. Unfortunately, all the footages we recorded were not at all conclusive. Again, 3 species (same total of individuals) were found in almost one month of recording, while during this amount of time almost half of the diving sightings were made. Some hypotheses can be made about this failure.

First, the different species are not attracted by the same bait, as they do not have the same diet. Ray species will be more attracted by small scale mollusks while some reef sharks would be attracted by small fish (Espinoza et al., 2015). But this assumption is not supposed to be the reason in our study, as we changed of bait several times, with the same results. Most of the time we use *Decapterus* spp. as bait, but we also tried with *Sardinella* spp. and some prawn species (*Penaeidae* spp). Sherman et al. (2018) recorded both *Taeniura lymma* and *Neotrygon orientalis* with BRUVS in the TARP with some *Sardinella* spp. as bait. Being aware of this success, as it was part of the bibliography of this study, we decided to switch bait. So, the fact that it did not work for us is quite surprising, given that the same methodology was used in the field.

The bait plume is also impacting the probability to attract the elasmobranchs (Langlois et al., 2010 & 2018). Logically, the bigger the plume is, the more chance there is of attracting individuals. Again, when the BRUVS were deployed during field sessions, we were looking for the current from the boat. Most of the time, no current was recorded, and for the few times there was some, we managed to set the structure with the bait right inside the current, to disseminate the smell of the bait in the environment. So normally, this assumption is not the answer of our issue with the BRUVS. Furthermore, the few sightings with the BRUVS can be induced by environmental conditions. As can be seen on the Figure 4.1 below, where the Blotched Fantail stingray (*Taeniurops meyeni*) was spotted in the PTMP, the water is murky, with poor visibility. Most of the recorded videos were made under those conditions, which are clearly not ideal for detecting elasmobranchs far from the camera. It is possible that we missed some individuals for this reason. As stated in several articles, clear water with high lighting increases the chance to observe biodiversity, but for our study, it can be the reason for the non-efficiency of the BRUVS (Langlois et al., 2010 & 2018 ; White et al., 2013). Moreover, even if the 2 PCA are with scuba-diving data, it is clear on the graphs that the visibility is impacting both abundance and specific richness. Thus, we can assume that the same process is happening for the BRUVS.

Therefore, multiple assumptions were made about the failure of the BRUVS in this study. We can not claim which one is answering to our concern. Probably, the addition of all those suppositions contributed to the failure of this sampling methodology.

Nevertheless, even if we did not incorporate the data from the BRUVS the few species spotted are important sightings. It is noted that two of the species, which are the Bentfin devil ray (*Mobula thurstoni*) and Blotched Fantail stingray (*Taeniurops meyeni*), were only recorded by the BRUVS. The footages of those two species highlight the fact that the biodiversity and the specific richness are higher than what we claim in this study, and further investigations need to be conducted. Additionally, a record of one hour at a certain depth is not representative of the behaviour of the individuals during the whole day (Langlois et al., 2010 & 2018).

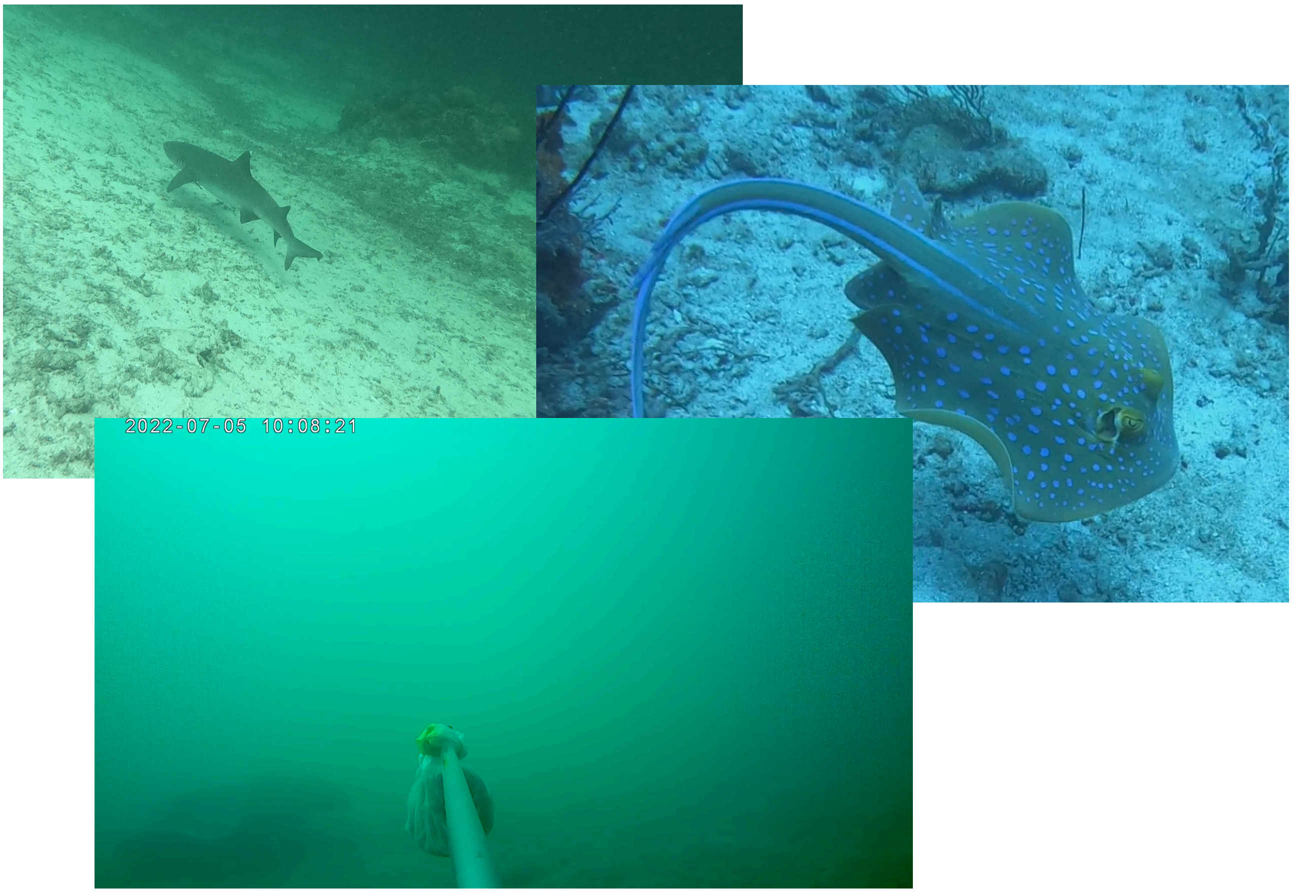


Figure 4.1: Comparison of pictures took while surveying. On the top left, a white tip reef shark (*Triaenodon obesus*), on the right side a blue-spotted ribbon tail ray (*Taeniura lymma*), both sighted while UVC. On the bottom left, the individual of Blotched Fantail stingray (*Taeniurops meyeni*) taken while using BRUVS. You can notice the difference of visibility in between UVC and BRUVS.

Moreover, the records were made in non-expected sampling areas : the Blotched Fantail stingray was discovered in PTMP, alone in the middle of the sand around 20m depth, and both the black tip reef shark (*Carcharhinus melanopterus*) and the Bentfin devil ray (*Mobula thurstoni*) were recorded on the same video at PS in shallow waters. The sight of the black tip reef shark is not surprising, as we found some in the TARP, the closest MPA, and it is one of the most widespread elasmobranch specie in Borneo's waters (Last et al., 2010). We can assume that, since the borders are nearby, populations of black tip reef sharks are surrounding the islands around TARP. But the devil ray is quite surprising. First, because it is not supposed to be attracted by the bait, even if the ray just passed by, more looking like a traveling behavior than a foraging one. Then, because from the article of Last et al. (2010), it is not supposed to be distributed on the western Sabahan coast. Finally, the Blotched Fantail stingray, from the same article, is not supposed to be present in the PTMP. But this species was recorded in some areas not far away (Last et al., 2010).

The use of BRUVS was supposed to allow us to detect large mobile species (Brooks et al., 2011). Using baited cameras was seen as useful because it does not interfere with both attracted individuals and benthic environment (Brooks et al., 2011 ; Osgood et al., 2019). In most of the studies, the species richness and the total number of individuals will be higher with BRUVs than UVC (Colton & Swearer 2010 ; Langlois et al., 2010 & 2018 ; Willis et al., 2000). Yet, in the present study, we can claim that the opposite outcome is the case, which was quite surprising. Even if in some studies abundance and species richness are higher with UVC than BRUVS (Colton & Swearer, 2010), the majority of the conducted studies recommends the use of BRUVS to assess abundance of target species, like elasmobranchs (Colton & Swearer, 2010 ; Gore et al., 2020 ; Langlois et al., 2010 & 2018 ; Last et al., 2010 ; McCauley et al., 2012 ; McNeil, et al., 2020 ; Osgood et al., 2019 ; Sherman et al., 2018 ; Speed et al., 2016 ; White et al., 2013 ; Willis et al., 2000). In the study of Colton & Swearer (2010), the UVC surveys recorded more individuals and more diversity in the species distribution, but they still recommend the use of BRUVS to assess mobile apex predators.

4.5. Elasmobranchs in the Malaysian society

To understand how elasmobranchs are seen in the Malaysian society, it is important to perceive the society in itself and their dependencies on marine biodiversity in general. The local people mostly fish for the local consumption, and do not target elasmobranchs (Ismail et al., 2019 ; Dent & Clarke 2015 ; Noh et al., 2019). Those are caught mostly bycatch, but kept as it provides additional incomes (Fatimah et al., 2017 ; Worm et al., 2013). MPAs are indeed helping in the elasmobranch conservation, but it is not enough. The local populations are unfortunately lacking of awareness about ecological issues, not only on sharks and rays matters (personal observations). From Noh et al. (2019) study, Sabahan fishermen usually have basic education level and a big experience in fisheries (the average experience is around 20 years). The indifference they have about ecological concerns such as plastic pollution, overfishing or global warming is not induced by the fact that they are disinterested but because of the lack of education. Malaysia being a developing country, the use of plastic is everywhere in demential proportions. The recycling of it after use is really low, and most people do not even throw the trashes in the bins. For example, in the TARP, a multi-use MPA focused on both conservation and tourism, a lot of plastic rubbish are still remaining on the beaches. If some hostel and restaurant crews were not cleaning them every morning, the amount of tourists will clearly be lower, as a beach full of litter is less attractive than a pristine beach. Also, you can observe the repercussions of this plastic pollutions underwater. When I was diving there, not a single dive I came out at the surface without plastic trashes. Sometimes it was with bags full of rubbish, definitely impacting in different ways the marine life (from my personal observations : fishes establishing homes in plastic bags, turtles eating them, coral reefs growing on hard plastic structures and many more…). Activities such as underwater clean-ups, awareness talks and conferences to raise their consciousness need to be more frequent. For the 48th anniversary of the TARP in July, actions like those were conducted and very conclusive for both side, either Sabah Parks authorities and tourists. But with this emergency situation that we are living, it is important to multiply activities to educate every kind of people, from the local people to the international tourists.

Figure 4.2 : Pictures taken from the fish market surveys in the State of Sabah. Elasmobranch diversity is important, as you can notice on these three pictures there is at least 7 different species of elasmobranch. On the top left, coral cat shark (*Atelomycterus marmoratus*), whitespotted wedgefish (*Rhynchobatus australiae*) and a cow nose ray species (*Rhinoptera* spp.) were for sale. On the top right, longtail butterfly ray (*Gymnura poecilura*), whitespotted wedgefish again, brown-banded bamboo shark (Chiloscyllium punctatum) and blue-spotted stingray (*Neotrygon orientalis*) species were exposed. On the bottom picture, spot-tail sharks (*Carcharhinus sorrah*) were presented to the consumers.

Malaysia is known to possess a huge number of elasmobranch species (Abd Haris Hilmi et al., 2020 ; Ahmad et al., 2017 ; Last et al., 2010). However, a certain amount of species present in the Malaysian waters still do not have any fishing quotas (Fowler et al., 1997 ; Noh et al., 2019). The overexploitation of marine resources is real, especially when you visit fish markets. While surveying the two biggest fish markets of the State of Sabah in term of landings (Kota Kinabalu and Sandakan), we noticed that the elasmobranch diversity is much higher than underwater (Figure 4.2). On the pictures above, you can observe that some species found in our study are also fish, such as the coral cat shark (*Atelomycterus marmoratus*) and the blue-spotted stingray (*Neotrygon orientalis*). We also noticed during our surveys endangered species, such as some devil ray species (*Mobula* spp.), whitespotted wedgefish (*Rhynchobatus australiae*) or big pelagic species like the great hammerhead shark (*Sphyrna mokarran*) (Friedman et al., 2018 ; Yano et al., 2005).

Additionally to the lack of awareness and the overexploitation, an issue about unregulated fisheries is also occurring in the Sabahan waters, both in MPAs or non-protected waters. During this month of September 2022, Sabah Parks and local authorities reported a drift net within the delimitation of the PSMP, with more than 35 sharks entangled. Two major conclusions are resulting from this sight. First, with this high number of dead sharks, it indicates that the elasmobranch populations are wealthy and seem to appreciate the habitats of Pulau Sipadan area, which is a good thing (Arai et al., 2015 ; Ali et al., 2018). Then, it highlights the fact that fishermen are still abusing of the marine biodiversity, even in protected areas. Another example was a personal sight of a drift net, in the unprotected waters nearby the TARP (PS, Figure 4.3 below).

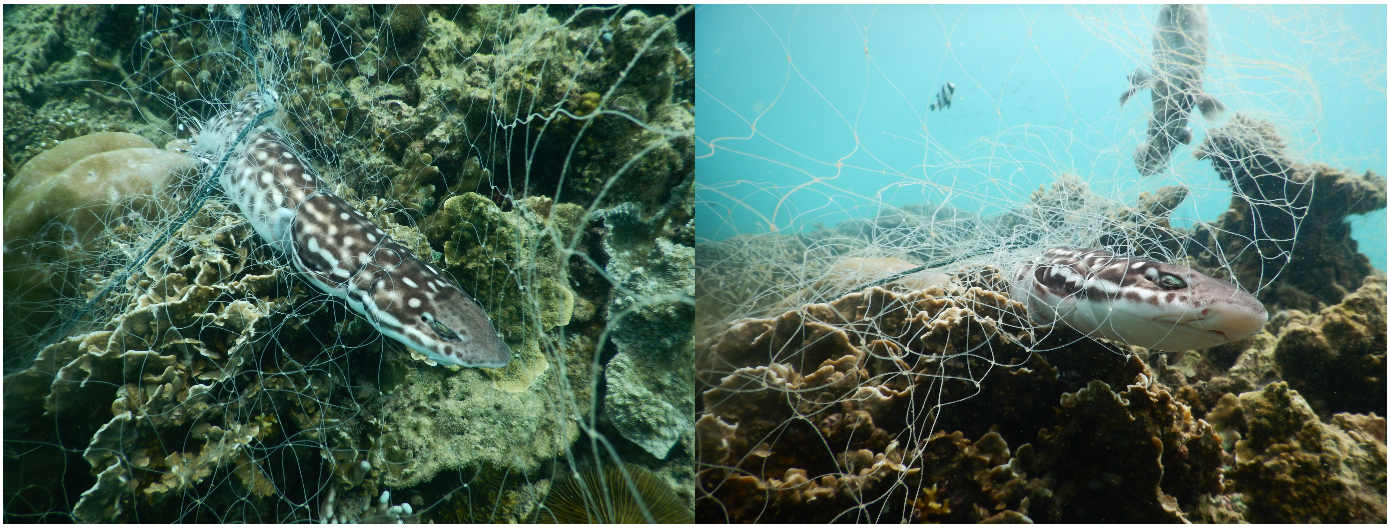


Figure 4.3 : Example of the damage of the drift nets on elasmobranch diversity. Here, a sight while diving of a coral cat shark (*Atelomycterus marmoratus*) entangled within the mesh of the drift net.

Previous studies established the importance of the MPAs on elasmobranch conservation (Hoyt, 2014 ; Knip et al., 2012 ; Ward-Paige, 2017). Within areas large enough to protect all life stages and with strong enforcement and management, the elasmobranch populations are in ideal conditions to prosper (Asaad et al., 2018 ; Claudet et al., 2008 ; Speed et al., 2018). To resolve all the issues mentioned earlier, the shark-diving tourism is a resilient and durable alternative (Macdonald et al., 2017 ; Vianna et al., 2018). Besides involving the local communities, transmitting them at the same time some ecological knowledge, it allows them to earn incomes without destructing the nature (Brunnschweiler, 2010). The socio-economic consequences of this shark-diving tourism has been proven in the Coral Triangle, and the example of PSMP is a local example at the Malaysian scale (Vianna et al., 2011, 2012 & 2018).

5. CONCLUSION

Most of the marine biodiversity has decreased in the past decades all over the world, and the island of Borneo is not an exception. Overfishing and inappropriate methods, such as fishing with dynamite (« fish bombing »), trawling and gill nets at forbidden fishing areas, are the main reasons of the decline of the marine organism populations in the Malaysian waters (Jakobsen et al., 2007 ; Nyanti et al., 1992). Illegal fishing practices within the TARP, by local fishermen on they small embarkations, also need a particular attention from the local stakeholders to enhance conservation plans for the MPA (Somaskanthan et al., 2016). The strong human activity close to the MPA impacts negatively all the marine life and ecosystems within its borders (Mohd et al., 2014), even though some coral reefs genera seem to be quite resilient to all those pollutants (Townsend, 2015). On the other hand, the TARP is quite well managed from an ecotourism point of view, where most of the tourists are glad of their experience within the marine park (Somaskanthan et al., 2016). Rangers are also doing an efficient job when some local fishermen are fishing inside the TARP.

We decided to combine different methods because each one has advantages and disadvantages. BRUVS surveys are useful to determine the relative abundance of a target species on a routine basis, while UVC is interesting due to the ability of the diver to move and sight elasmobranchs in complex areas (Colton & Swearer, 2010). Unlike the bibliography stated, the BRUVS appeared inefficient to sight elasmobranch individuals for our study. From our data collected by UVC, we recorded several elasmobranch species, but not as much as we wanted and we knew present within the Sabahan waters (Abd Haris Hilmi et al., 2020 ; Ahmad et al., 2017 ; Last et al., 2010). Two dominant species were recorded, *Taeniura lymma and Neotrygon orientalis*, and the elasmobranch abundance and specific richness was higher in MPAs than non-protected waters.

However, for all the MPAs covered in this study, there exists fishing communities living in coastal villages adjacent the MPAs and even along the boundaries of the MPAs - which is thought to negatively influence the elasmobranch biodiversity in general and the expected spillover benefits of the MPAs. MacNeil et al. (2020) demonstrated that for an MPA to be effective, especially as an elasmobranch sanctuary, the MPA should be a 'very large' (a certain minimum size, due to the known wide swimming range of pelagic elasmobranchs). Based on our observations and this paper, we recommend an extension for the current Sabahan MPAs to aid the connectivity of adjacent coral reefs, which will increase the effectiveness of the MPAs. Moreover, there is never enough studies undertaken on elasmobranchs, especially in locations where anthropic pressures are a real threat for them. Further studies on elasmobranch biodiversity must be conducted, either within the boundaries of MPAs, in the non-protected waters or during fish market surveys.

6. ACKNOWLEDGEMENTS

I would like to express my gratitude to the Borneo Marine Research Institute (BMRI) and Sabah Parks to host me during my stay on the Borneo island. A special thanks is going to my two supervisors there : Dr B. Mabel Manjaji-Matsumoto and Dr Nasrulhakim Maidin, without whom I could not do much. Without them, my whole internship would have been totally different. The daily help they gave me was priceless and I will remember that. Another thanks goes to the Sabah Parks staff based on Pulau Manukan (TARP), especially Mr Elvin, Awang, that were supportive for the logistic, and Jack and Boh, my diving buddies. I also acknowledge the people from the Tropical Research and Conservation Center (TRACC) of Pulau Pom-Pom to let us come and undertake our experiment with them. I would also like to thank Dr Karim Erzini, which was more than helpful for the preparation part in Faro, the writing of the research proposal, and provided me some cameras.

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