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Fish and fishing monitoring methods and indicators in Marine Protected Areas in Tunisia

Emna Ben Lamine

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UNIVERSITE COTE D'AZUR
- UFR Sciences
Ecole Doctorale de Sciences
Fondamentales et Appliqués

INSTITUT NATIONAL
AGRONOMIQUE DE TUNIS
Ecole Doctorale Sciences et Techniques
de l'Agronomie et de l'Environnement

THESE

pour obtenir le titre de

Docteur en Sciences

de l'UNIVERSITE Côte d'Azur et de l'INSTITUT National Agronomique de Tunis

Discipline: Sciences de l'Environnement/ Sciences Halieutiques

présentée et soutenue par

Emna BEN LAMINE

Méthodes et indicateurs de suivi de la pêche et des peuplements de poissons dans les Aires Marines Protégées en Tunisie

Fish and fishing monitoring methods and indicators in Marine Protected Areas in Tunisia

Thèse dirigée par

Patrice FRANCOUR & Mohamed Salah ROMDHANE

Soutenance prévue le 5 décembre 2017 devant le jury composé de:

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Remerciements

Et voilà que quatre ans sont passées, depuis 2014, nombreuses sont les personnes qui ont apporté leur précieuse aide pour l'élaboration et l'amélioration de ce travail, et ce dans différentes phases. C'est pour cela que je tiens à remercier :

D'abord, mes deux directeurs de thèse, Pr Mohamed Salah Romdhane et Pr Patrice Francour, pour leurs conseils précieux, Je tiens à leur exprimer ma profonde reconnaissance pour m'avoir prodigué leurs conseils techniques et pour leur soutien scientifique, et

Les deux rapporteurs Pr Philippe Lenfant et Pr Eric Feunteun, ainsi que tous les membres du jury pour avoir pris la lourde tâche d'évaluer ce travail.

Les travaux de terrain étalés sur trois ans ont été réalisables grâce à l'aide de nombreuses personnes. Je tiens à remercier les plongeurs volontaires membres de l'association tunisienne Alysse Plongée, pour leur dévouement et intérêt pendant l'apprentissage et l'application de la méthode FAST. Mourad Saidane, Sofiène Ben Aissa, Slim Souihi, Raja Ben Aissa, Omar Ben Hassine, Oussema Ben Lamine et Fathi Bouzouia, vous êtes les premiers plongeurs volontaires à avoir fait le comptage poissons pour les AMCPs tunisiennes ! Je vous suis bien reconnaissante de votre soutien, votre mobilité et flexibilité aux conditions de terrain, votre bonne humeur même quand il fallait se réveiller à 4 h30 du matin, et la bonne ambiance à chaque fois !!

Les sorties de terrain pour plonger en Tunisie en dehors d'un club de plongée agréé, ne sont pas si évidente que ça. Les sorties ont été rendu possible avec le club nautique de Tabarka certaines fois. Aussi, les immersions ont été possible grâce aux embarcations du bureau d'étude Okianos et de l'association de l'école de pêche Tabarka, et aux embarcations privées de Mahdi Aguir, Naceur Ben Lamine & Noureddine Ben Afia. Je remercie également tous les moniteurs de plongée et les personnes qui ont assuré la sécurité à bord. Notamment, Wissem Houiji, Abderrahmane Mliki, Lasaad Zouaoui, Aymen Abidi & Mahdi Aguir.

Je tiens à remercier également Imed Abbasi, Ilhem Ben Maiz, Hamdi Hmissi, Walid Abbasi, Lasaad, Rzouga, et tous les autres pêcheurs artisanaux et récréatifs qui ont accepté de me faire part de leur quotidien, leurs captures & leurs problèmes. La liste est longue !

Je suis également bien reconnaissante à mes collègues de l'Agence de Protection et d'Aménagement du Littoral (APAL) et du Centre Régional des Activités pour les Aires Spécialement Protégées (SPA/RAC) : Saba Guellouz, Anis Zarrouk, Souha Elasmî, Atef Limam et Yassine Ramzi Sghaier, pour leurs encouragements continus. Cela compte énormément pour moi.

Tout au long de cette thèse, j'ai eu le plaisir de faire partie de trois différentes familles :

- La famille Unité de Recherche Ecosystèmes et Ressources Aquatiques. J'y remercie vivement Mme Janhani, Mme Frida, Chiheb et Moez, ainsi que mes amies Dhekra, Leila et ma petite Sameh.

- Mon autre famille de co-tutelle, ECOMERS, les échanges du repas de midi étaient un plaisir à chaque fois !! Je remercie toute l'équipe. Je remercie également les « poulettes » Sylvaine, Claudia et Elisabeth (Best title team ever !!), mais aussi Paolo, Simona, Guilia, Patricia, Antonio, Fabricio, Pierre, Daniella et Jean Michel.

- Ma famille de l'arrondissement des pêches et de l'aquaculture de Monastir, j'y remercie vivement Mr Ridha Amimi, le chef d'arrondissement, mes collègues Naima, Marwa, Latifa et Latifa, Jamila et Mohamed. Je remercie également Mr Bechir Ben Aicha, le commissaire régional de l'agriculture à Monastir.

Je remercie vivement aussi Jaqueline Gauthier-Debernardi pour avoir corrigé l'introduction et la discussion version française !!

Je remercie aussi mes amis Aida et Julien, ainsi que toutes les personnes qui ont contribué de près ou de loin au bon déroulement de cette thèse !

Le fruit d'un long travail de thèse est tel qu'on a envie de le dédier fièrement à sa petite famille, Mama et Baba, il n'y a jamais assez de mots... C'est grâce à votre confiance, votre dévouement et votre patience que j'en suis là. Je ne vous remercierai jamais assez pour avoir supporté mon absence, suivi le rythme fou de mes études, mes recherches et de mon travail (parfois en même temps !!), des sorties terrain dans les quatre coins de la Tunisie et ailleurs !!! Surtout, je vous ne remercierai jamais assez pour m'avoir donné l'exemple à suivre de courage et de persévérance ! Je dédie également cette thèse à ma sœur Sana, mon frère Oussema et à mon beau-frère Jawhar, pour être toujours là, à l'écoute, merci pour tout !

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Publication

Ben Lamine E., Guidetti P., Romdhane M.S. and Francour P. In Press. Fish assemblages along the coasts of Tunisia: a baseline study to assess the effectiveness of future Marine Protected Areas: Accepted. 2017. Mediterranean Marine Science. <http://dx.doi.org/10.12681/mms.14206>

Ben Lamine E., Di Franco A., Romdhane M.S. and Francour P. Can citizen science contribute to fish assemblages monitoring in understudied areas? The case study of Tunisian marine protected areas: Accepted. 2017. Estuarine, Coastal and Shelf Science, 2016.

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Ben Lamine E., 2014. Synthèse sur les techniques et les indicateurs de suivi écologiques des poissons dans les îles Kuriat. Contrat MedMPANet. RACSPA publi, 40p.

ملخص

يعتبر إنشاء المحميات البحرية الساحلية أداة رئيسية للتصرف المستدام في التنوع البيولوجي، بالإضافة إلى كونها وسيلة للحفاظ على الكائنات الحية المميزة والنظم الايكولوجية. في اطار احداث شبكة المحميات البحرية في البلاد التونسية، يتطلب وضع خطط التصرف مراقبة علمية متواصلة للحصول على معلومات موثوقة. وتأتي هذه الخطوة مع الحاجة إلى اختيار المناهج والمؤشرات التي تعتبر مهمة لتقييم فعالية المحميات البحرية. لذلك، فإن هذه الأطروحة تهدف إلى اختيار واختبار طرق ومؤشرات تقييم الثروات السمكية من أجل اقتراح استراتيجية مراقبة علمية لأربعة مناطق محمية بحرية في تونس. وقد تم اختيار الأساليب والمؤشرات من قائمة المراجع وفقا لجدواها، فعاليتها، وتكلفتها ومدى ملاءمتها مع أهداف المحميات البحرية. تم تجميع البيانات عن الأسماك وأنشطة صيدها باستخدام خمس طرق: اثنتان باستعمال الغوص وثلاثة للصيد البحري الساحلي: (1) الطريقة المصادق عليها: المسح ذو العرض المتغير؛ (2) طريقة متابعة الأسماك المعدة للتطبيق من طرف الغواصين المتطوعين؛ (3) الاستبيانات مع الصيادين ومراقبة المصائد؛ (4) الصيد التقليدي التجريبي؛ (5) متابعة الصيد البحري باستعمال تقنية التصوير. وتظهر النتائج بعض النقاط البارزة التي سيقع استعمالها لاحقا لاقتراح استراتيجية المتابعة العلمية ومنها: (1) فائدة اعتماد نماذج أخذ العينات المناسبة في الوقت المناسب لاستنتاج عوامل التأثير قبل استنتاج فعالية المحميات لاختبار الفرضيات في المستقبل، (2) النسب المنخفضة نسبيا للكتلة الحيوية للأسماك في جميع المواقع المدروسة بالمقارنة مع المناطق البحرية المحمية الأخرى في البحر الأبيض المتوسط (3) الإمكانات الفاعلة لعلوم المواطن (مشاركة المتطوعين) لمراقبة الأسماك في تونس باستعمال طريقة سهلة الاستخدام، بعد اختبار تناسبها مع الطريقة المصادق عليها (4) نسبة عالية من ممارسة الصيد الممنوع (الصيادون الترفيهيون الذين يبيعون صيدهم)، في المواقع المدروسة، (5) التنافس بين الصيد البحري التقليدي و الصيد غير المشروع خاصة على النطاق التجاري (6) انخفاض الكتلة الحيوية، ونسبة الأسماك الكبيرة الحجم باستخدام طريقة الصيد التجريبية. ولذلك، فإن الاستراتيجية المقترحة لمتابعة الأسماك والصيد البحري في المحميات البحرية التونسية تعتمد على التعاون بين العلماء وأصحاب المهنة (الصيادين، والغواصين الترفيهيين)، والمتصرفين في هذه المناطق المحمية، والتي يمكن أن تكون مفيدة في رفع مستويات القبول والمشاركة في المناطق البحرية المحمية. مما يمكن أن يساعد كثيرا في احداث شبكة المحميات البحرية التونسية.

كلمات مفاتيح: متابعة علمية- محميات- صيد تقليدي- ترفيهي- البحر الأبيض المتوسط

Abstract

Scientific monitoring is the key to reliable information in Tunisian future MPAs, where management plans are being established. This crucial step comes with the need to choose appropriate methods, metrics and indicators for monitoring parameter that are important to assess MPAs effectiveness. Therefore, the purpose of this manuscript is to select, adapt, test and propose fish assemblage and fishing monitoring methods and indicators in order to propose a monitoring strategy for four Tunisian future MPAs (locations). Selection of methods and indicators from literature was made according to their feasibility, cost-effectiveness and suitability with future MPAs objectives. Therefore, data on fish assemblage and fishing activities were collected using five methods: (1) Transects with variable width (TVW); (2) Fish Assemblage Sampling Technique (FAST); (3) Questionnaires and landing catch monitoring; (4) Experimental fishing; (5) photo-surveillance method. Results shows some highlights that were considered for proposing the monitoring strategy: (1) the usefulness of adopting appropriate sampling models, BACI ("Before After Control Impact"), using standard TVW, to test hypotheses related to the effectiveness of the future MPAs, (2) the relatively low values of biomass in all studied locations in comparison with other Mediterranean MPAs (3) the high potential of citizen science for fish monitoring in Tunisia using easy-to-use FAST method, after testing its coherence with standard TVW method, (4) a high percentage of illegal fishing practice (recreational fishers that commercialize their catch), in the studied locations, (5) the competition of recreational and illegal fishing with commercial-small scale (CSS) one, on vulnerable and high economic value species, and (6) low biomasses, carnivores proportions, large fish proportion in catch of CSS using experimental fishing method. Therefore, the proposed strategy for fish and fishing monitoring for Tunisian future MPAs is based on the collaboration between scientists, stakeholders (fishermen, recreational divers) and managers, which can be useful to implement high compliance and MPAs acceptance levels, especially when it comes to creating a future MPAs network.

Key words: Monitoring, small-scale, recreational, fish biomass, South Mediterranean

Résumé

Le suivi scientifique dans les AMPs est la clé pour le recueil information fiable dans les future AMPs de la Tunisie, où des restrictions d'usages et des plans de gestion sont en cours de mise en place. Cette étape cruciale le long des côtes tunisiennes viens avec le besoin en méthodes, métriques et indicateurs appropriés pour le suivi des paramètres utiles pour évaluer leurs efficacités. Le but de ce travail est de sélectionner, adapter, tester et proposer des méthodes et des indicateurs de suivi des assemblages de poissons et des activités de pêche, afin de proposer une stratégie de suivi pour quatre futures AMPs tunisiennes. La sélection des méthodes et des indicateurs de la bibliographie a été réalisée en fonction de leur faisabilité, de leur rentabilité et de leur adéquation avec les objectifs des futures des AMPs. Par conséquent, les données sur l'assemblage de poissons et les activités de pêche ont été recueillies en utilisant cinq méthodes: (1) Transects à largeur variable (TVW); (2) Fish Assemblage Sampling Technique (FAST); (3) Questionnaires et suivi des débarquements; (4) pêche expérimentale; (5) photo-surveillance. Les résultats des suivis réalisées entre 2014 et 2016, ont été pris en compte lors de proposition de la stratégie de suivi, notamment: (1) l'utilité d'adopter des modèles d'échantillonnage appropriés, BACI ("Before After Control Impact"), en utilisant la méthode standard des UVC, pour tester des hypothèses liées à l'efficacité des AMP futures, (2) les valeurs faibles de la biomasse dans toutes les AMPs étudiés par rapport à celles méditerranéennes (3) le potentiel des sciences participatives pour les suivi des assemblages de poissons en utilisant une méthode FAST, après avoir testé sa cohérence avec la méthode standard , (4) un pourcentage élevé de pratique de pêche illégale (pêcheurs récréatifs qui commercialisent leurs captures), (5) la compétition de la pêche récréative et illégale avec la pêche artisanale, sur les espèces vulnérables et de valeurs économiques élevées, et (6) des biomasses faibles, proportions de carnivores, grande proportion de poisson dans la capture des pêcheurs artisanaux, en utilisant la méthode de pêche expérimentale. Par conséquent, la dite stratégie proposée pour le suivi dans les futures AMPs tunisiennes repose sur la collaboration entre les scientifiques, les parties prenantes (pêcheurs, plongeurs récréatifs) et les gestionnaires, ce qui peut être utile pour assurer un certain niveau d'acceptation des AMPs, surtout quand il s'agit de créer un réseau tunisien d'AMPs.

Mots clés: Suivi, artisanal, récréatif, biomasse, poissons, Méditerranée du Sud

Chapter I: General Introduction

Marine Protected Areas (MPAs) in the Mediterranean Sea

The Mediterranean Sea is characterized by a high species richness, associated with a high proportion of endemism (Bianchi *et al.*, 2012). It is also one of the most threatened seas where biodiversity undergoes rapid alteration (Coll *et al.*, 2012). This makes it one of the hotspots of biodiversity (Bianchi *et al.*, 2017). Coastal zones shelter the most productive and threatened ecosystems (such as the *Posidonia oceanica* meadows). Current conservation efforts appear to be insufficient facing the rapid change in biodiversity under anthropogenic impacts, introduction of non-indigenous species and climate change (Coll *et al.*, 2012; Bianchi *et al.*, 2012; 2017).

Although the creation of Marine Protected Areas (MPAs) is considered as the most effective way to protect biodiversity, the goal of protecting at least 10% of the Mediterranean Sea by the year 2012, is still far from reach (PISCO & UNS, 2016). Mediterranean coastal MPAs cover only 6.5% of the total surface area of the Mediterranean Sea and the total area of marine reserve (no-take zones) covers only 0.04% of the total area of MPAs (PISCO & UNS, 2016). In addition, the southern and eastern parts of the Mediterranean Sea are not protected enough (PISCO & UNS, 2016, Giakoumi *et al.*, 2017), and even in the north western, many MPAs are only “paper parks”, where there is no management core (Francour *et al.*, 2001; Mora *et al.*, 2006; Guidetti *et al.*, 2008; Montefalcone *et al.*, 2009; Rife *et al.*, 2013; Scianna, 2017). Well-managed MPAs are widely recognized as an effective mean to improve catches of Commercial Small Scale (CSS)¹ fisheries (e.g. Di Franco *et al.*, 2014, Guidetti *et al.*, 2014, Prato *et al.*, 2016). In these MPAs, there is an increase in catch size in general and in high trophic level predator catches that have higher economic value (Prato *et al.*, 2016; 2017). To assess adequately changes in coastal fish species and assemblages, and to manage pressures on biodiversity, it is essential to develop adequate monitoring programs, especially when it comes to sustain an activity of great economic importance in the Mediterranean as CSS fisheries (Forcada *et al.*, 2009; FAO, 2016).

¹ Commercial Small Scale fisheries (CSS) : fishing activities that are performed using ancestral techniques, boats of total length less than 12 meters, Guyader *et al.*, 2007 often synonymous with sustainable fishing

Coastal fishing² in Mediterranean Sea and in Tunisian coastal waters

In the Mediterranean Sea, there is an overall decline in fisheries from 1 087 000 tonnes in 1994 to 787 000 tonnes in 2013 despite the increase in the fleet and the improvement of fishing techniques (FAO, 2016). CSS fisheries are not the ones that provide the highest catches, but they are those that provide more jobs, either directly or indirectly. Indeed, CSS fishing fleet accounts for 80% of the total Mediterranean fleet (FAO, 2016).

Fishing is one of the oldest activities in the Mediterranean Sea. Ancient art present in many Mediterranean countries testifies about the link between prehistoric and modern situation suggesting that shallow depths areas (3-12 m) have lost high trophic level predators, which they used to shelter (from the first to the fifth century) (such as the grouper *Epinephelus marginatus* and the monk seal *Monachus monachus* (Guidetti & Michelli, 2011)) as well as their corresponding ecological roles (Sala, 2004). Nowadays, and according to FAO, over 30% of Mediterranean and black Sea stocks are overexploited or depleted (Pauly *et al.*, 1998, 2002; FAO, 2016). This degradation can be mainly due to overfishing, since the end of the 20th Century through the emergence of the first collapse of stocks from the late 1980s (Pauly *et al.*, 1998, 2002). At the same time, global change can accelerate fish size reduction in the global catches (Pauly & Cheug, 2017).

Tunisia is the country where fishing accounts for the highest number of direct jobs at the national scale representing ~23% of the total direct jobs in fisheries sector at the Mediterranean Scale (FAO, 2016). Yet, it is the country where the average economic value of landing per employee and per fishing operation is among the lowest (~4\$) (FAO, 2016). CSS fishing in Tunisia, as in the Mediterranean Sea, is performed using passive fishing gears that can be selective or not (e.g. combined nets, gillnets, pots and traps, etc.) targeting a large variety of species. However, locally, there is little detailed, reliable and exploitable information about catch (e.g. detailed species identification, individual size and bycatch) and socio-economic dimensions (Gaamour *et al.*, 2005; Khalfallah, 2015; Chemmam-Abdelkader, 2004). In Tunisia, the decline of trawling catches (Zarrad *et al.*, 2004) and CSS fisheries (CAR/ASP & PNUE-PAM, 2014; Halouani *et al.*, 2015) is apparent through the decrease in caught fish size. Moreover, overall catches decreased despite the increase

² Coastal fishing: any fishing activity occurring in the coastal zone (Lloret *et al.*, 2016)

in fishing effort (Zarrad *et al.*, 2004; DGPA, 2016). This suggests the revision of current fisheries management models and the use of solutions goes along with both sustainable use of resources and fishermen's interests. "Biological rest" financed by the Tunisian ministry of agriculture is one of the solution proposed to manage fisheries since the year 2009 in the golf of Gabes (Law n°2009-17 of 16th Marsh 2009). Ben Haj Hmida *et al.*, (2014) found that "biological rest" campaigns improved tawling catches after three years. Artificial reefs were also immersed in the same locality to face the illegal trawling (at shallow waters below 50 meters depth). Scientific studies are ongoing to test their effectiveness (DGPA, 2016).

In this context, CSS fishing in Tunisia (more than 80% of the fishing fleet) is in competition with many other fishing activities on the same ressources (Jaber *et al.*, 2000), noticeably the illegal trawling, and other illegal coastal fishing. Another emergent pressure in recent years in Tunisia is recreational³ fishing (Khalfallah, 2015; Besta, 2016). It is practiced mainly by spear guns, line or trolling (from the shore line or from a boat). The evolution of fishing gears, their low cost and the availability of information on the practice of recreational fishing (social networks, etc.) make recreational fishing increasing in popularity in the Mediterranean (Lloret *et al.*, 2016) and in Tunisia (Tunisian Sport Fishing Federation, 2010). There are very few data about recreational fishing. The global fisheries assesement in the world, including in the Mediterranean, generally omitted recreational fishing activities, the number of fishers, their catch and their bycatch (Pauly & Zeller, 2016). The current global reconstructed catch is about 1 mt per year (Pauly & Zeller, 2016). Recreational fishing is declining in developed countries, but increasing in developing ones. This sector is largely missing from official reported data, despite FAO requests explicitly allowing inclusion of recreational catch data in their reports. This activity, however, generates an estimated 40 billion USD per year of global benefits, involves between 55 and 60 million persons, and generates about one million jobs worldwide (Pauly & Zeller, 2016). Recreational fishing is not deemed to generate direct commercial production, yet they can contribute significantly to coastal economies (Pawson *et al.*, 2008; Gaudin & De Young 2007; FAO, 2016). Recreational catches have long been thought very small catches compared to commercial fishing. This is far from being the

³ Recreational fishing is fishing of living marine organisms where the catch is solely destined for personal or family consumption and not for commercialization (Pawson *et al.*, 2008)

case in the last years all over the world, including in Tunisia (Pauly & Zeller, 2016). Reconstruction of global catches has shown that proportions of recreational and illegal fishing are not negligible in the world (Pauly & Zeller, 2013, 2016) and in Tunisia (Halouani *et al.*, 2015). In the North Mediterranean Sea, some studies characterized recreational fishing in some MPAs, quantifying fishing impacts and comparing it with CSS fishing, e.g. in France (Lloret *et al.*, 2008; Albouy *et al.*, 2010; Hussein *et al.*, 2010; Rocklin *et al.*, 2011; Lloret & Font, 2013; Marengo *et al.*, 2015), in Spain (Morales-Nin *et al.*, 2005) and in Turkey (Unal *et al.*, 2010; Tunca *et al.*, 2016). In Tunisia, recreational fishing practitioners members of the “Fédération nationale de la chasse sous-marine” was estimated to 3000 fishers during the year 2015. Other estimations showed that a recreational fisher catch on average 5 kg during summer in the north coasts of Tunisia (Khalfallah, 2013; Besta, 2015). Catch reconstruction showed a total estimated catch of 132 T per year for all recreational fishers along Tunisian coasts for the year 2010 (Halouani *et al.*, 2010).

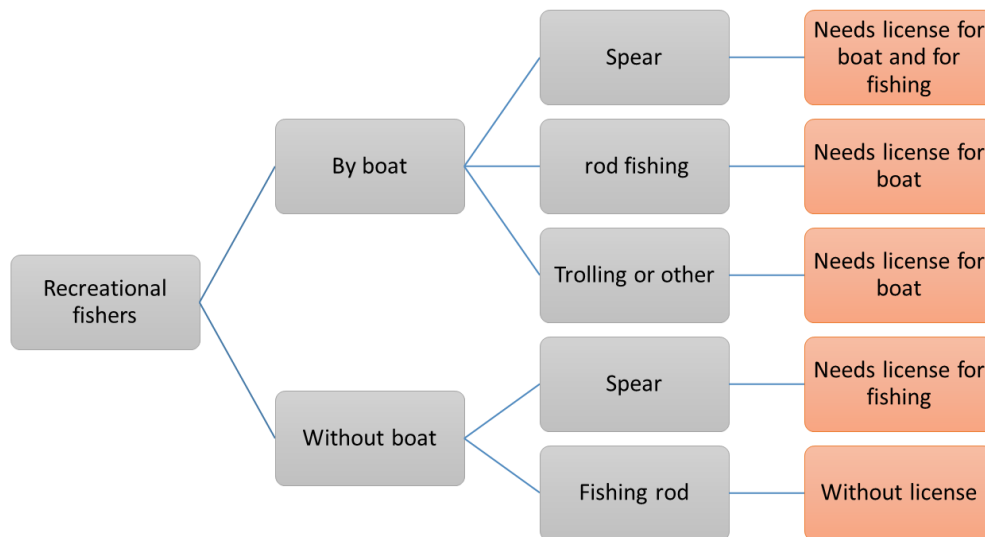


Figure I.1. Diagram of recreational fishing regulation along Tunisian coasts

Regulation and management of coastal fishing

Despite its regulation, coastal fishing in Tunisia remains illegally practiced and the laws governing it are mostly not respected by users. Illegal Unregulated Unreported (IUU)⁴ fishing is a frequent phenomenon in Tunisian waters and its consequences are disastrous. It is an obstacle to the

⁴ Illegal fishing: all professional or recreational fishing is carried out outside the Ministerial Decree of September 20, 1994 and September 28, 1995 (of the Tunisian Ministry of Agriculture).

sustainable management of resources (Khalfallah, 2013; CAR/ASP & PNUE-PAM, 2014). So far, official landing monitoring does not include recreational catches, although recreational fishing licenses are delivered by the ministry. Information currently collected is the total weight in kilograms per genus or per species. This does not allow to extract reliable information about exploitable stocks. Besides, the size is not included in official reports although it is a relevant information for the control. In the last years, catch size are usually smaller than legal catch size (DGPA, 2016).

In this context, fisheries management in Tunisia is carried out in two ways: catch or effort management. The catch is managed by enforcing minimum catch size, while the management of the fishing effort mainly concerns the limitation of gears and fishing fleet. Nevertheless, for different reasons, these two approaches have not prevented the overexploitation of coastal stocks. It is the case for the European hake *Merluccius merluccius* (Zarrad *et al.*, 2000). Thus, a strategic study was conducted to reorganize and improve the fishing sector in Tunisia (DGPA, 2016). Conclusions reached by scientists within this study suggest that MPAs could be a realistic solution. They should be created and enforced in harmony with the adopted Ecosystemic Approach (DGPA, 2016). Well-managed MPAs are an effective management tool to restore depleted stocks and improve fishing yields (Shin & Cury, 2000; Francour, 2005). They can promote sustainable use of the resource, guaranteeing biodiversity preservation. In terms of protection of marine resource from exploitation, a MPA aims at reducing fish mortality by fishing. Thus, monitoring of fish assemblages is the first way to evaluate MPAs effectiveness.

Toward the creation of MCPAs⁵ network along Tunisian coasts

Tunisia is one of the Mediterranean countries that has marine reserves (with no-take zones) since the year 1977, in two national marine parks (La Galite and Zembra) with a total area of 140 km² (Gabrié *et al.*, 2012). Marine and Coastal Protected Areas (MCPAs) or MPAs is a national priority declared by the government during the Ministerial Council of Marsh 23rd, 1998. The “Agence de Protection et d’Aménagement du Littoral” (APAL) was in charge of creation MCPAs in

⁵ MCPA: Protected Marine and Coastal Area: the naming by the Tunisian Law of MPAs, with the same definition, same status of protection, modalities and objectives of management

Tunisia since January 3rd, 2000 (Zarrouk, 2017). Initiatives undertaken by APAL in creating MCPAs national network have begun in the year 2000 by strengthening its expertise in the management of protected areas. APAL has begun by planifying a program to identify “vulnerable sites” to protect. Once they are identified, several management plans were conducted (e.g: APAL, 2010; APAL, 2011, APAL, 2015). Once “vulnerable site” concept adopted legally and public familiarized with it, the APAL introduced the MCPA approach (APAL, 2010). Then, activities have been carried out in “vulnerable sites” of “La Galite”, “Zembra et Zembretta” and “Cap Negro-Cap Serrat”. Other approaches are also concerning other sites: islands of the Kerkennah archipelago, Kneiss islands, Tabarka and the Kuriat islands (APAL, 2010; Zarrouk, 2017). However, they are still only structuring actions of effective management within future MPAs creation (CAR/ASP & PNUE-PAM, 2014; 2015; DGPA, 2016).

Since 2009, the Tunisian State has laws specific to the administration and management of these territories with a law dedicated to MCPAs (n ° 2009- 49). However, this law will remain unenforced as long as the creation decrees are not promulgated, as the state has every interest in rapidly giving the management bodies the regulatory intervention capacity they need to carry out their mission (CAR/ASP & PNUE-PAM, 2015). Since the 20th of May 2014, other texts have been promulgated. Specifically, the conditions for the establishment of the national committee for MCPA creation, its missions and priorities. The promulgation of the implementation decrees will be the next step towards the fulfillment of the legal status of Tunisian MCPAs. Subsequently, the management of protected decree sites will have to take place going beyond the scientific missions undertaken so far (APAL, 2011, CAR/ASP & PNUE-PAM, 2015). The management scenarios proposed in the management plans will favor the protection of sites (through the monitoring and management of effective management actions) while allowing important socio-economic activities such as sustainable fishing and controlled tourism (APAL, 2010; APAL 2011; CAR/ASP & PNUE-PAM, 2015).

In Tunisia, as in many other Mediterranean countries, MPAs will be created to conserve and protect biodiversity, but also to improve and promote sustainable socio-economic activities in the long term (CAR/ASP & PNUE-PAM, 2014; 2015; Zarrouk, 2017). MPAs are no longer

considered to be the closed protected area where no human activity is permitted but rather as an area where protection and human uses can coexist together. A balance between preservation and human use is sought. A MPA may include different areas with different levels of protection: partially protected, where some activities are prohibited, but other activities are permitted and / or regulated (multi-use areas), or fully protected, where all extractive and recreational activities are forbidden, except scientific monitoring. Fully protected areas are also known as non-harvest areas or integral protection areas (PISCO & UNSA, 2016). Total protection against extracting activities generally has far greater long-term ecological, economic and social benefits than partial or zero protection (Guidetti *et al.*, 2014). Ongoing studies suggest that fully protected areas may also provide resilience to several environmental threats, including climate change (PISCO & UNSA, 2016).

Up to date, Tunisian coasts has 7 AMCPs in project: the Galite archipelago, Tabarka, Cap Negro Cap Serrat, Zembra and its islets, the Kuriat islands, the Kneiss islands and the islands northeast of Kerkennah Map of Figure I-1). This MCPA network should help to preserve the marine biodiversity of the Tunisian coasts and ensure the sustainability of marine and terrestrial resources.

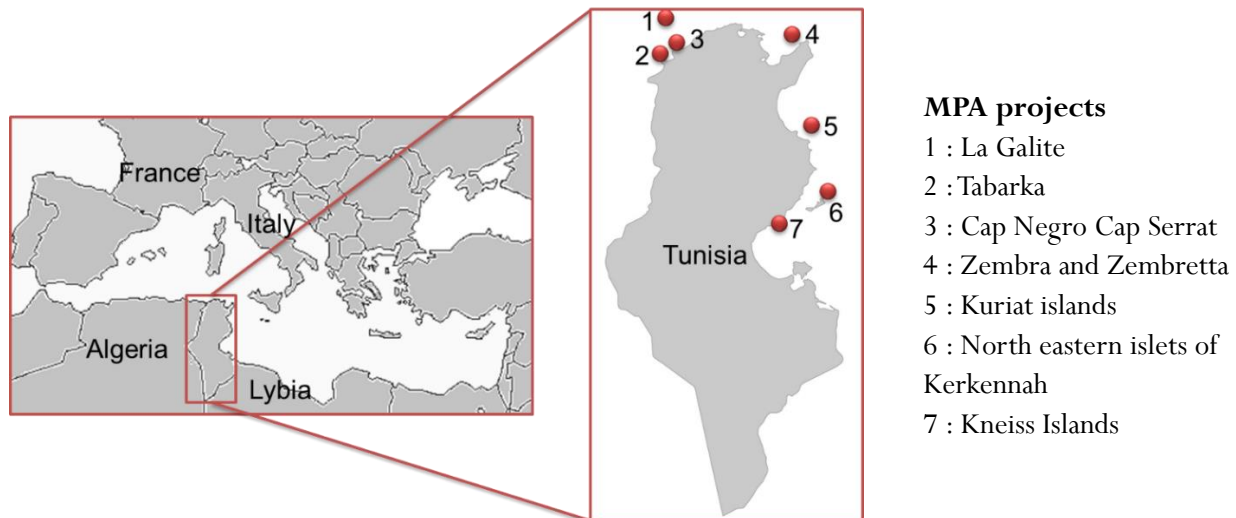


Figure I.2. Situation map of Tunisia in the Mediterranean, with a focus on the network of AMCPs being created, numbered from north to south.

(1) **“La Galite” archipelago:** the archipelago once housed the monk seal and other species. In Galite and its Galitons we find the endemic brown algae, bioindicating pure waters, *Cystozeira stricta*, very vulnerable in the Mediterranean (APAL, 2001), *Pinna nobilis* of the crustaceans of the genus *Homarus vulgaris*, the Mediterranean Slipper Lobster *Syllarides latus* and the Red lobster *Palinurus elephas* species highly sought after by fishermen (APAL, 2001)

(2) **Tabarka:** Fishing and tourism are the two main activities in the coastal area of Tabarka. Trawl fishing and inshore fishing occupy the largest part of the fleet based at the port of Tabarka, which is the only port in the region. As the Tabarka region is located in the northern fishing zone, it benefits from several incentives for the development of the fishery.

(3) **Cap Negro Cap Serrat:** Since 2003, the management of the Cap Negro-Cap Serrat littoral area has been carried out by the Coastal Protection and Management Agency (APAL, 2011). Fishing is artisanal and coastal. The inventory of fish fauna was made from landings in ports, data from the official landing statistics, and questionnaires from fishermen (WWF, 2007).

(4) **The island of Zembra and its islets** also have a very important biodiversity: 200 species of algae and 200 benthic animal species. In 1977, the national park of Zembra and Zembretta was created (Decree 77-340 of 1 April 1977). It is also known as a refuge for a large number of colonies of gray shearwater (Ouerta & Limam, 2008). In the same year, Zembra was included in the list of the UNESCO Biosphere Reserve International Network of the UNESCO MAB Program (Man and the Biosphere). Thus, Zembra and Zembretta became the first national park to be established in Tunisia and having both national and international status. The fishing is deep-sea and the fire. Inventories of fish fauna on the basis of underwater visual counts were carried out in 2002 (Ramos Espla *et al.*, 2002).

(5) **The Kuriat Islands**, located off Monastir are known for their conservation capital for the *Caretta caretta* turtles (Jribi & Bradai, 2014). The two islands are flat, with the coastal shores, protected from immersion in part by the permanent benches of posidonia. This space is now threatened by great pressure on the fisheries resources of its waters, but also by facilities built on the small Kuriat hosting unmanaged large tourist flows (CAR/ASP & PNUE-PAM, 2014). They are

surrounded by vast posidonia meadows and lawns of *Cymodocea*. The inventory of fish fauna was made from landings in ports, data from the General Directorate of Fisheries, as well as questionnaires from fishermen (Hached, 2012) and on the basis of UVC counts in 2008 (Ramos Espla *et al.*, 2010).

(6) Northeast islands of the Kerkennah Islands, located in the northern part of the Gulf of Gabes opposite the town of Sfax, they constitute a little studied ecosystem. They offer a very interesting fishery potential, particularly with high octopus vulgaris octopus productivity, *Sepia officinalis* cuttlefish and *Diplodus*. They constitute, by far, the main concentration zone of the Cherfias (a typical artisanal fishery in this area for the capture of coastal species) (APAL, 2010).

(7) Kneiss Island: is an island in the Gulf of Gabes, off the coast of the city of Sfax. The project being created is justified by its ornithological importance. It is known for its colonies of migratory birds (APAL, 2010).

Indicators in MPAs

According to the Convention on Biological Diversity (CBD), which Tunisia ratified since 1978, with its seven protocols (included protocol ASP/DB), and the Directive 2008/56 / EC of 17 June 2008, aiming at protecting and restoring ecosystems based on the establishment of a good ecological status, it was recommended to develop indicators and metrics to assess the loss of biodiversity (Levrel *et al.*, 2010). Indicators and metrics can be a useful tool for to communicate environmental scientific data to managers and decisions makers. In the context of MPAs, reference values establishment requires information from areas that have long been protected and considered to be in equilibrium. When these data are not available, the trend over time of metrics and indicators is used. This is often the case for evaluating the effect of fishing (Trenkel & Rochet, 2003, Jenning, 2005). Indicators and metrics can be used to diagnose and assess risks to ecosystem changes (Amand *et al.*, 2004).

Metrics and indicators often allow to highlight the impact of fishing and the performance of management measures. Indicators for managers should be understandable by non-experts. The performance of metrics and indicators lies mainly in their statistical properties and their sensitivity

to the studied question. Metrics and indicators were also very used to evaluate MPAs effectiveness (Balief & Pelletier, 2011). Fish assemblages and fishing indicators can be used to assess reserve effect on the long term.

Issues and objectives of the thesis

The census of ichthyofauna in Tunisia has been linked for years to fisheries, using destructive sampling techniques or monitoring fishing landings (trawl, seiners or CSS), and not with underwater visual censuses (UVC); example: Le Danois (1925), Azzouz (1973) on trawling funds, Bouhleb (1973) on the Gadidae, Ben Nacer *et al.*, (2007) and Gharbi *et al.*, (2008) on Mullidae, Fezzani-Serbaji *et al.*, (2006) on Atlantic horse mackerel, Gharred & Ktari (2001) on Blennidae, Hattour *et al.*, (2004, 2005) on pelagic fish stocks, Bradai (1990, 2005) on Scorpaenidae, Zarrad *et al.*, (2001, 2004) on benthic trawls performance, Chemmam-Abdelkader *et al.*, (2004) and Chemmam-Abdelkader (2004) on dentists, Fehri-Bedoui *et al.*, (2002) on Mugilidae, Romdhani *et al.*, (2013, 2014) on the Gadidae, Fassatoui *et al.*, (2009, 2010; 2011; 2012) on the pageot. The Tunisian ichthyofauna is dominated by teleosteans (80%) (Bradai *et al.*, 2004). Elasmobranches account for 19% of all species. The whole represents about 49% of the fish fauna of the Mediterranean, 325 out of 657 (Bradai *et al.*, 2004). The 325-fish species inventoried are distributed over 221 genera, 114 families and 30 orders (Bradai *et al.*, 2004). The specification distinguished 279 Atlanto-Mediterranean species, 23 endemic species, and 23 non-indigenous species (e.g. *Siganus luridus* in the Gulf of Gabes) (Bradai *et al.*, 2004). In Tunisia, along the coastal zones (0-20 meters deep), monitoring of fish assemblages and fishing activities faces many challenges:

(1) First, the lack of comprehensive empirical data on coastal fish is highlighted in MPAs. Some UVC have been conducted to provide data on vulnerable species but have not been replicated over space and over time,

(2) Standard methods for visual census are training demanding, usually requiring scuba diving to allow certainty in fish identification and accuracy in estimating size. The lack or

unavailability of scientific divers, which makes it more difficult and with high cost to organize field missions.

(3) Monitoring of fish assemblages underwater has been limited to traditional monitoring programs organized within puntual projects to the limits of available funds.

(4) Monitoring of fish species was carried out on the basis of landing monitoring, since the ultimate objective is to assess fish for exploitation purposes.

(5) The legal framework in Tunisia for scientific diving is not very clear. Scuba diving is an activity in development with recreational diving clubs. Despite the legal framework of diving is not very clear to promote scientific sampling, recreational diving is an activity in development in many cities. There are 426 recreational divers belonging to 12 diving clubs distributed along the Tunisian coast (Tunisian federation of underwater activities FAST, 2017). If they are interested, their involvement in monitoring fish assemblages can be a cost-effective solution if their contribution proves to be reliable. This has potential to explore for the monitoring of marine resources in general and fish stocks in all coastal zones and in future Tunisian MPAs in particular.

The development of a MPAs network is accompanied by a need for tools to assess the performance of MPAs and fishing pressures. MPAs creation is accompanied by scientific monitoring of biotic and abiotic resources, in particular those that are linked to MPAs conservation objectives. The choice of appropriate methods for monitoring fish assemblages and fishing activities in a given MPA is an important step, especially when it comes to a future MPAs network.

The main objective of our work is to adapt, propose and test methods and indicators for the monitoring of fish assemblage and fisheries along Tunisian future AMPs (Tabarka, Cap Negro-Cap Serrat, Zembra archipelago, and the Kuriat Islands). Thus, for this work, in addition to two UVC monitoring methods, we tested 3 other methods of monitoring the fishing pressure:

- (1) Transects with variable width
- (2) Fish Assemblage Sampling Technique (FAST)

- (3) Questionnaires to all fishermen in future study MPAs. This would give an overview of the pressure exerted, what activity, what techniques, and what motivation they have to practice fishing (CSS, recreational, other ...)
- (4) Experimental fishing with CSS fishermen, to collect "before" data using the same gear as fishermen, where CSS fishing is likely to be permitted
- (5) Tracking illegal fishing, using the photo-surveillance method

Thus, within the PhD objective and using different methods applied, and different metrics and indicators calculated, different hypotheses have been tested according to five s/objectives (each s/objective corresponds to a chapter):

S/objective 1: bibliographic review, about fish and fishing methods, metric and indicators

S/objective 2: Start an experimental design before impact for three future AMPs using the standard UVC method

Hypothesis 1. Is there a significant difference between the interior (future protected area) and the outside (unprotected zone) in fish assemblage measurements (density, biomass and size distribution)?

S/objective 3: In the light of the lack of data in coastal areas and the lack of scientific divers, propose and test an easy to use method in collaboration with volunteer divers

Hypothesis 2. Is the standard UVC method comparable to the easy to use UVC method (FAST)?

Hypothesis 3. Are the results of scientifically trained volunteers (STV) significantly different from scientific divers (SD)?

S/objective 4: addressing coastal fishing pressure: understanding both the ecological and socio-economic characteristics of coastal fishing in Tunisia

Hypothesis 4. Use of questionnaires and landing: Is there a significant difference between inshore (commercial, small-scale, recreational and illegal) fisheries using mean catch, average trophic level (MTL), index of intrinsic vulnerability (IVI) and the average price of catches (MCP)?

Hypothesis 5. Use of the experimental fishing method: Is there a significant difference between the interior (future protected area) and the outside (un-protected zone) in artisanal fisheries measures (biomass, species richness, Proportion of large size (LP) and Proportion of carnivores (CP))?

S/objective 5: testing photo-surveillance method

Chapitre I : Introduction Générale

Les Aires Marines Protégées (AMPs) Méditerranéennes

La mer Méditerranée se caractérise par une forte richesse en espèces, associée à une proportion importante d'endémisme (Bianchi *et al.*, 2012). C'est aussi l'une des mers les plus menacées et la biodiversité y subit une altération rapide (Coll *et al.*, 2010). Cela en fait l'un des hotspots de la biodiversité (Bianchi *et al.*, 2017). Les écosystèmes côtiers sont parmi les écosystèmes les plus productifs et les plus menacés (tels que les herbiers de *Posidonia oceanica*). Les efforts actuels de conservation semblent affaiblis face au changement rapide que connaît la biodiversité sous l'influence combinée des impacts anthropiques (pollution, pêche illégale...etc.), de l'introduction d'espèces non-indigènes et du changement global (Coll *et al.*, 2010 ; Bianchi *et al.*, 2012 ; 2017).

Bien que la création d'Aires Marines Protégées (AMPs) soit considérée comme un moyen efficace pour protéger la biodiversité, l'objectif de protéger au moins 10% de la Méditerranée en 2012, n'est pas encore atteint. Les AMPs côtières méditerranéennes ne couvrent que 6.5% de la surface totale de la mer Méditerranée et les zones de protection renforcée (zones sans prélèvement) couvrent seulement 0.04% de la totalité des AMPs (PISCO & UNS, 2016). En outre, les secteurs Sud et Est de la mer Méditerranée ne sont pas suffisamment protégés (PISCO & UNS, 2016 ; Giakoumi *et al.*, 2017), et même dans le nord-ouest, beaucoup d'AMPs ne sont que des « paper parks » car il n'y a aucune équipe de gestion (Francour *et al.*, 2001 ; Mora *et al.*, 2006 ; Guidetti *et al.*, 2008 ; Montefalcone *et al.*, 2009 ; Rife *et al.*, 2013 ; Scianna, 2017). Les AMPs, quand elles sont bien gérées, sont reconnues comme un moyen efficace pour améliorer les captures des pêcheries artisanales (e.g. Di Franco *et al.*, 2014, Guidetti *et al.*, 2014, Prato *et al.*, 2016) par l'effet réserve qu'elles entraînent. Dans ces AMPs, on observe une augmentation de la taille des poissons pêchés (pêche artisanale) mais surtout une augmentation des captures en prédateurs de hauts niveaux trophiques ayant une valeur économique plus élevée (Prato *et al.*, 2016 ; 2017). Pour évaluer correctement les changements dans les espèces et assemblages côtiers et gérer les pressions qui s'exercent sur la biodiversité, il est essentiel de développer des programmes de suivis adéquats,

surtout quand s'agit de pérenniser une activité d'une grande importance économique en Méditerranée comme la pêche artisanale⁶ (Forcada *et al.*, 2009 ; FAO, 2016).

Pêche côtière⁷ en Méditerranée et en Tunisie

En Méditerranée, on assiste à un déclin global des pêcheries, de 1 087 000 tonnes en 1994 jusqu'à 787 000 en 2013 malgré l'augmentation du nombre de bateaux et l'amélioration des techniques de pêche (FAO, 2016). Dans toute la Méditerranée, les pêcheries artisanales⁸ ne sont pas celles qui produisent les captures les plus élevées au fil des années mais ce sont surtout celles qui assurent le plus d'emplois, directement ou indirectement. En effet, la pêche artisanale méditerranéenne compte 80% de la flotte totale de pêche tous types confondus (FAO, 2016).

L'exploitation des ressources halieutiques est une activité économique très ancienne. L'art ancien présent dans de nombreux pays côtiers méditerranéens suggère que les zones de faibles profondeurs (3-12 m) ont perdu les prédateurs de hauts niveaux trophiques de grande taille, qu'ils abritaient autre fois (du I^{er} au V^{ème} siècle) (comme le mérrou brun *Epinephelus marginatus* et le phoque moine *Monachus monachus* (Guidetti & Michelli, 2011), ainsi que leurs rôles écologiques correspondants (Sala, 2004 ; Prato *et al.*, 2013). De nos jours, et d'après la FAO, plus de 30% des stocks de la Méditerranée et de la mer noire sont surexploités ou épuisés (FAO, 2016). Cette dégradation pourrait être due essentiellement à la surpêche dont les conséquences se sont fait ressentir depuis la fin du XX^{ème} siècle à travers l'apparition des premiers effondrements de stocks à partir de la fin des années 1980 (Pauly *et al.*, 1998 ; 2002 ; FAO, 2016). En même temps, le changement global pourrait accentuer la diminution de la taille des captures à l'échelle mondiale (Pauly & Cheung, 2017).

La Tunisie est le pays où l'activité de pêche assure le plus grand nombre d'emplois directs à l'échelle nationale, représentant ~23 % de la somme des emplois directs du secteur pêche dans

⁶ La pêche artisanale : activité de pêche qui se fait avec des techniques artisanales, des barques de longueur totale inférieure à 12 mètres, (Guyader *et al.*, 2007) souvent synonyme de pêche durable

⁷ La pêche côtière : toute activité de pêche qui s'exerce dans la zone côtière (Lloret *et al.*, 2017)

toute la Méditerranée (FAO, 2016). Pourtant, c'est le pays où la valeur économique moyenne de débarquement par employé et par opération de pêche est parmi les plus faibles (FAO, 2016). La pêche artisanale tunisienne, à l'image de la pêche méditerranéenne, se caractérise par l'utilisation des engins de pêche passifs et sélectifs ou non (par exemple, les filets trémail, les filets maillants, les pots et les pièges, etc.) ciblant une grande variété d'espèces. Cependant, il existe peu d'informations généralisées, fiables et exploitables au niveau local sur la caractérisation de leurs captures en détail (identification précise, taille et poids individuels, espèces pêchées en faibles quantités) (Gaamour *et al.*, 2005 ; Khalfallah, 2015 ; Chemmam-Abdelkader, 2004). En Tunisie, le déclin de la plupart des pêcheries au chalut (Zarrad *et al.*, 2004) et des pêcheries artisanales (CAR/ASP & PNUE-PAM, 2014 ; DGPA, 2016) est visible à travers la réduction de la taille des captures, la diminution de la diversité des espèces pêchées et par la diminution des quantités pêchées annuellement malgré l'augmentation de l'effort de pêche (DGPA, 2016). Cela conduit à penser à la révision des modèles de gestion du passé et à favoriser le recours à des solutions plus conformes aux besoins. Le repos biologique financé est un exemple de gestion des pêcheries appliqué depuis l'année 2009 au golfe de Gabès (Loi n° 2009-17 du 16 mars 2009, relative au régime du repos biologique dans le secteur de la pêche et son financement). En 2014, Ben Haj Hmida *et al.*, ont montré que la rentabilité des principales espèces exploitées par chalutage benthique s'est améliorée, suite à trois campagnes (réparties sur trois ans) de repos biologique. Une autre approche qui a été appliquée pour pallier au problème du chalutage illégal (à des profondeurs inférieures à 50 mètres), était l'immersion de récifs artificiels. Des études sont en cours pour l'évaluation de leurs performances, dans le golfe de Gabès (DGPA, 2016).

Dans cette perspective, la pêche artisanale en Tunisie (plus de 80% des embarcations de l'activité de pêche) se trouve en conflit avec d'autres types de pêche sur les mêmes ressources (Jabeur *et al.*, 2000). On peut notamment évoquer la pêche illégale au chalut, la pêche à la tartaronne « Kiss » et aux filets dérivants ou « Derra », qui sont des pratiques récurrentes tout au long des côtes tunisiennes (DGPA, 2016). Un autre type de pêche côtière qui s'est installé dans les zones côtières tunisiennes et qui ne peut passer inaperçu ces dernières années, c'est la pêche

récréative⁹ (Khalfallah, 2015 ; Besta, 2016). Elle est pratiquée principalement à l'arbalète (chasse sous-marine) et à la ligne ou à la traîne (à partir du bord ou d'un bateau de plaisance). L'évolution des engins de pêche récréative, leur faible coût et la disponibilité des informations sur sa pratique font qu'elle gagne en popularité de jour en jour (Lloret *et al.*, 2016). Il existe très peu de données sur ce type de pêche, les statistiques de pêche les plus précises existant dans le monde, Méditerranée incluse, ont très souvent négligé le nombre de pêcheurs récréatifs, leurs captures et leurs rejets (Pauly & Zeller, 2016). Des études récentes de reconstruction des captures ont considéré que la pêche récréative présente approximativement 1 MT à l'échelle globale, que la pêche récréative est en déclin dans les pays développés et qu'elle est en essor dans les pays en développement (Pauly & Zeller, 2016). Malgré le manque de données mondiales et locales sur les captures et l'impact en général, c'est une activité qui génère approximativement 40 billions USD par an de bénéfices, implique entre 55 et 60 millions de personnes et génère environ 1 billion d'emplois dans le monde (Pauly & Zeller, 2016). Ce type de pêche n'est pas sensé générer une production commerciale directe, pourtant, il peut contribuer significativement aux économies côtières (Pawson *et al.*, 2008 ; Gaudin & De Young, 2007, FAO, 2016). Les captures récréatives ont pour longtemps été considérées comme des captures très minimes par rapport à la pêche professionnelle. C'est loin d'être le cas au cours des dernières années partout dans le monde (Pauly & Zeller, 2013 ; 2016), la Tunisie comprise (Halouani *et al.*, 2015).

Au nord de la Méditerranée, un certain nombre d'études a été mené pour caractériser la pêche récréative dans des AMPs, quantifier son impact et la comparer avec la pêche artisanale, en France (Lloret & Font, 2013 ; Lloret *et al.*, 2008 ; Hussein *et al.*, 2010 ; Marengo *et al.*, 2015 ; Rocklin *et al.*, 2011 ; Albouy *et al.*, 2010), en Espagne (Morales-Nin *et al.*, 2005) et en Turquie (Unal *et al.*, 2010 ; Tunca *et al.*, 2016). En Tunisie, le nombre de pêcheurs récréatifs adhérant à la fédération nationale de chasse sous-marine a été estimé à 3000. Un pêcheur récréatif pêche en moyenne 5 kg par jour en été dans la région nord (Khalfallah, 2013, Besta, 2015). La reconstruction

⁹ La pêche récréative : toute activité de prélèvement d'organismes vivants marins où la capture est uniquement vouée à la consommation personnelle ou familiale et pas pour la commercialisation (Pawson *et al.*, 2008)

des captures montre que la pêche récréative prélève une quantité estimée de 132 T/an en 2010 (Halouani *et al.*, 2015).

Réglementation et gestion de la pêche côtière

Malgré sa réglementation, la pêche côtière en Tunisie demeure mal pratiquée et les lois qui la régissent sont le plus souvent non respectées par les pêcheurs. La pêche Illégale Non déclarée Non réglementée (INN¹⁰) est un phénomène fréquent dans les eaux tunisiennes et ses conséquences n'en sont pas moins désastreuses. Il s'agit d'un obstacle à la gestion durable des ressources (DGPA, 2016 ; Khalfallah, 2013 ; CAR/ASP & PNUE-PAM, 2014). La pêche INN n'est jusqu'ici pas prise en compte dans les débarquements officiels de pêche. Ceux-ci sont suivis selon un système qui comporte plusieurs failles qui font que les données ne sont pas exploitables pour extraire des données fiables renseignant sur l'état de l'exploitation des ressources (exemple : identification des poissons au niveau de l'espèce, taille des captures). Les informations actuellement collectées relèvent uniquement du poids total en kilogrammes par espèce, malgré l'importance de l'information sur la taille de capture, souvent inférieure à la taille de capture légale (DGPA, 2016). En plus des débarquements qui ne sont pas suivis (hors ports et hors circuit de commercialisation), les statistiques officielles ne comprennent pas les captures de la pêche récréative, bien que les licences de pêche récréative soient livrées par le même ministère (arrondissements de pêche et d'aquaculture, ministère de l'agriculture) (Khalfallah, 2013 ; Besta, 2015 ; DGPA, 2016).

¹⁰ La pêche illégale en Tunisie : il s'agit de toute pêche professionnelle ou récréative qui se fait en dehors des décrets ministériels du 20 Septembre 1994 et du 28 septembre 1995 (du Ministère de l'Agriculture Tunisien).

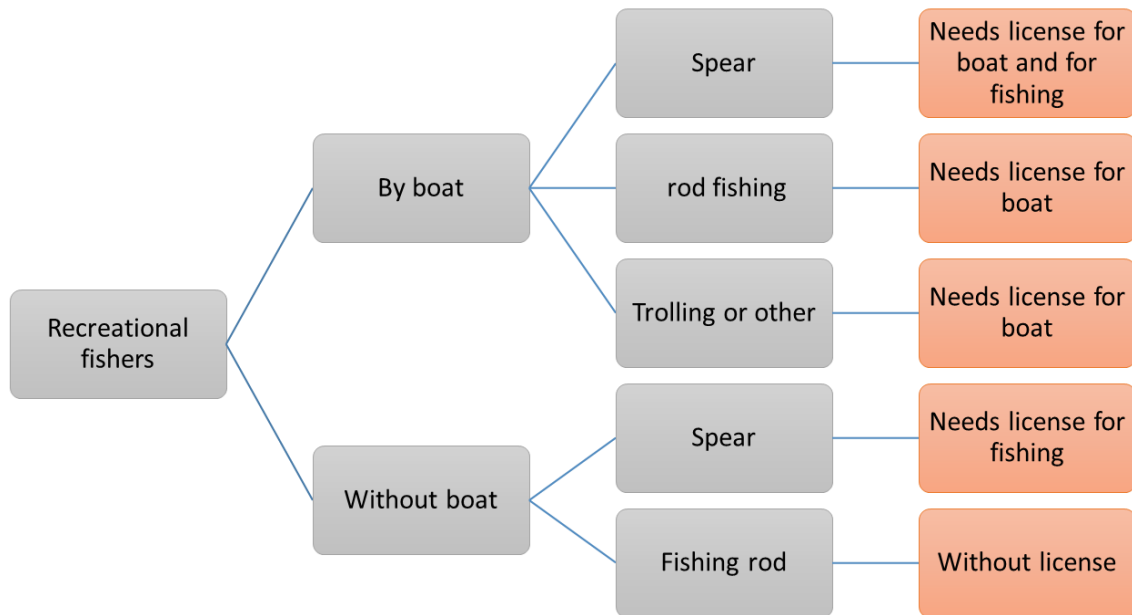


Figure I.3. Diagramme des licences nécessaires pour l'exercice de l'activité de pêche récréative en Tunisie (source : Arrêté du ministre de l'agriculture du 20 septembre 1994 et du 28 septembre 1995 relatif à l'exercice de la pêche à la plongée, de la pêche sous-marine de plaisance, et de la pêche de loisir).

Dans le contexte actuel d'intensification de l'effort de pêche sur les zones côtières, la gestion de la pêche en Tunisie s'effectue classiquement sous deux formes : gestion des prises ou de l'effort de pêche. Les prises sont gérées en imposant des tailles de captures alors que la gestion de l'effort de pêche concerne principalement la limitation des équipements. Néanmoins, pour différentes raisons, ces deux approches n'ont pas empêché la surexploitation des stocks côtiers (exemple, le merlu *Merluccius merluccius* (Zarrad *et al.*, 2000). Ainsi, comme suggéré dans l'étude stratégique du secteur pêche et aquaculture (DGPA, 2016), et en accord avec les principes de l'approche écosystémique adoptée, les AMPs bien gérées sont perçues comme un moyen efficace de gestion pour restaurer les stocks épuisés et améliorer les rendements de pêche, (Shin & Cury, 2000; Francour, 2005) et promouvoir ainsi l'utilisation durable de la ressource, tout en garantissant la préservation de la biodiversité. En matière de pêche et de ressources halieutiques, une AMP vise la diminution des mortalités par pêche. Ainsi, le suivi des ressources et des pressions dans les AMPs est devenu au cours des dernières années un enjeu scientifique majeur. Celui-ci est perçu comme le premier moyen d'évaluer l'efficacité des AMPs.

Vers la création de réseaux d'AMCPs¹¹ le long des côtes tunisiennes

La Tunisie compte parmi les pays méditerranéens qui disposent de réserves marines strictement interdites de prélèvement depuis 1977. Elle en possède dans deux parcs nationaux (La Galite et Zembra) leur surface globale étant de 140 km² (Gabrié *et al.*, 2012). La création d'Aires Protégées Marines et Côtières (AMCP) ou AMPs est devenue une priorité nationale, annoncée par le gouvernement tunisien au cours du Conseil Ministériel Restreint du 23 mars 1998 et réaffirmée au cours du Conseil Interministériel du 26 août 2000. Le 3 janvier 2000, l'Agence de Protection et d'Aménagement du Littoral (APAL), a été chargée par le ministère de l'Environnement et de l'Aménagement du Territoire tunisien, de la création des AMPs en Tunisie (Zarrouk, 2017). Les initiatives ainsi menées par l'APAL, visant la création d'un réseau national d'AMCPs, ont commencé au début des années 2000 pour renforcer son expertise en matière de gestion d'Aires Protégées. L'APAL a ainsi procédé en mettant en place une planification progressive qui lui a permis d'identifier dans un premier temps des sites dits « sensibles ». Elle a par la suite élaboré des études de base pour acquérir les connaissances nécessaires à leur gestion, réalisant plusieurs plans de gestion dans le cadre d'un programme national de gestion des zones sensibles. Une fois l'existence et le concept de « zone sensible » adopté dans le cadre d'une politique nationale (législativement et territorialement) et les différents publics familiarisés avec le concept, l'APAL a introduit l'approche AMCP (APAL, 2010). Depuis, des activités régulières sont menées sur la Galite et ses îlots, Zembra et ses îlots, et Cap Negro-Cap Serrat. D'autres démarches ont également concerné et concernent toujours d'autres sites : les îlots Nord-Est de l'archipel de Kerkennah, les îles Kneiss, Tabarka et les îles Kuriat. Toutefois, il ne s'agit encore que d'actions structurantes situées en amont d'une gestion effective en vue de la création d'AMPs (CAR/ASP & PNUE-PAM, 2014 ; 2015 ; DGPA, 2016).

Depuis 2009, l'Etat Tunisien dispose de textes de lois spécifiques régissant l'administration et la gestion des futures aires protégées avec une Loi dédiée aux AMCP (Loi n°2009-49). Cette loi restera cependant non-applicable tant que les décrets d'exécution ne seront pas promulgués, l'Etat ayant tout intérêt à rapidement donner aux organismes gestionnaires la capacité d'intervention réglementaire dont ils ont besoin pour réaliser leur mission. (CAR/ASP & PNUE-PAM, 2015).

¹¹ AMCP : Aire Marine et Côtière Protégée: la dénomination par la Loi Tunisienne d'une AMPs, avec la même définition, même statut de protection, modalités et objectifs de gestions

Depuis le 20 mai 2014, d'autres textes d'application de cette loi ont été promulgués (Décret n° 2014-1845 du 19 mai 2014 et Arrêté du ministre des affaires locales et de l'environnement du 28 avril 2017), notamment en ce qui concerne les conditions de composition du comité national des AMCPs, ses missions, ses priorités et sa constitution. La promulgation des décrets de création sera la prochaine étape vers l'établissement des statuts juridiques d'AMCPs tunisiennes. Par la suite, c'est la gestion des sites décrétés protégés qui devra prendre place allant au-delà des missions scientifiques ponctuelles entreprises jusqu'ici (APAL, 2011, CARASP & PNUE-PAM, 2015). Les scénarios de gestion proposés dans les plans de gestion privilégieront la protection des sites (par la surveillance et la conduite des actions de gestion efficaces) tout en autorisant des activités socio-économiques importantes telles que la pêche durable et le tourisme contrôlé (APAL, 2011, APAL, 2010, CAR/ASP & PNUE-PAM, 2015).

En Tunisie, comme dans de nombreux autres pays méditerranéens, les AMPs seront créées pour conserver et protéger la biodiversité, mais aussi pour améliorer et promouvoir des activités socio-économiques durables sur le long terme (CAR/ASP & PNUE-PAM, 2014 ; 2015 ; Zarrouk, 2017). Une AMP n'est plus considérée comme aire « sous cloche », fermée où aucune activité humaine n'est autorisée, mais plutôt comme une zone où la protection et les utilisations humaines peuvent coexister. Un équilibre entre la préservation et l'utilisation humaine est recherché. Selon cet objectif, une AMP devrait comprendre deux types de zones avec deux niveaux de protection : partiellement protégée, où certaines activités sont interdites, mais d'autres activités sont autorisées et/ou réglementées (zones à usages multiples), ou entièrement protégées, où toutes les activités de prélèvement et récréatives sont interdites, excepté le suivi scientifique. Les zones entièrement protégées sont également appelées zones de non-prélèvement ou zone de protection intégrale (PISCO & UNSA, 2016). La protection totale contre les activités extractives entraîne généralement des avantages écologiques, économiques et sociaux sur le long terme (Guidetti *et al.*, 2014, PISCO & UNS, 2016). Des études en cours suggèrent que des zones entièrement protégées peuvent apporter une résilience à plusieurs menaces environnementales, y compris contre les changements climatiques (PISCO & UNSA, 2016). Dans les zones à usages multiples, l'impact des activités humaines devrait être surveillé, en particulier les activités touristiques et la pêche.

Le littoral tunisien compte à ce jour, 7 projets de création d'AMCPs : l'archipel de la Galite, Tabarka, Cap Negro-Cap Serrat, l'archipel de Zembra, les îles Kuriat, les îles Kneiss et les îlots Nord Est de Kerkennah (carte de la figure I-2). Ce réseau d'AMCPs devrait permettre de préserver la biodiversité marine des côtes tunisiennes et d'assurer l'utilisation durable des ressources marines et terrestres.

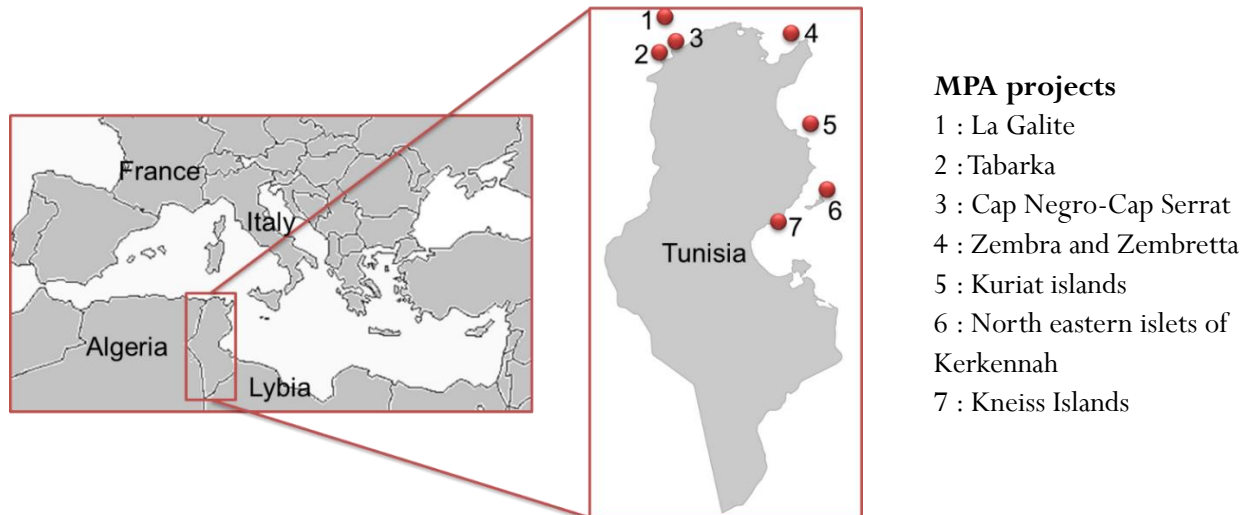


Figure 0I.4. Carte de situation de la Tunisie en Méditerranée, avec un focus sur le réseau d'AMCPs programmé pour la décennie 2010-2020 en cours de création, numéroté du nord vers le sud (APAL, 2010, modifié)

(1) La Galite : C'est une Aire Spécialement Protégée d'Importance Méditerranéenne (ASPIM) depuis 2001 et future Aire Marine et Côtière Protégée. C'est également un site qui se caractérise par une très riche biodiversité marine et terrestre en plus d'un patrimoine historique et paysager exceptionnel. L'archipel abritait autrefois le phoque moine ainsi que d'autres espèces. Dans la Galite et ses Galitons on retrouve l'algue brune endémique de Méditerranée, bio-indicatrice des eaux pures, *Cystoseira stricta*, très vulnérable en Méditerranée (APAL, 2010), *Pinna nobilis*, des crustacés du genre *Homarus vulgaris*, la cigale de mer *Syllarides latus* et surtout la langouste rouge *Palinurus elephas* espèce très recherchée par les pêcheurs (APAL, 2010).

(2) Tabarka : La pêche et le tourisme sont les deux principales activités dans la zone côtière de Tabarka. La pêche au chalut et la pêche côtière occupent la plus grande partie de la flottille basée au

port de Tabarka, celui-ci est le seul port de la région. La région de Tabarka étant située dans la zone Nord de pêche, elle bénéficie de plusieurs mesures d'encouragement pour le développement de la pêche. L'inventaire de la faune ichthyologique a été réalisé à partir des comptages visuels sous l'eau (APAL, 2011).

(3) Cap Negro Cap Serrat : Depuis 2003, l'étude de gestion de la zone sensible Cap Negro-Cap Serrat a été réalisée par l'Agence de Protection et d'Aménagement du Littoral (APAL). La pêche y est artisanale. L'inventaire de la faune ichthyologique a été réalisé à partir des débarquements dans les ports, des données de la Direction Générale de pêche (WWF, 2007).

(4) L'île de Zembra et ses îlots enregistrent aussi une biodiversité très importante : 200 espèces d'algues et 200 espèces animales benthiques. Elles sont connues aussi car elles constituent un refuge pour un nombre important de colonies de puffins cendrés (Ouerta & Limam, 2008). En 1977, le parc national de Zembra et Zembretta a été créé (décret 77-340 du 1er avril 1977). La même année, Zembra a été inscrite sur la liste du réseau international des réserves de la Biosphère du Programme MAB de l'UNESCO. Ainsi, Zembra et Zembretta sont devenues le premier parc national à être créé en Tunisie et ayant à la fois un statut national et international. La pêche y est hauturière et au lamparo. Des inventaires de la faune ichthyologique sur la base de comptages visuels sous l'eau ont été réalisés en 2002 (Ramos Espla *et al.*, 2002).

(5) Les îles Kuriat, situées au large de Monastir sont connues pour leur capital de conservation des tortues *Caretta caretta* (Jribi *et al.*, 2006 ; Jribi & Baradi, 2014). Les deux îles sont planes, aux littoraux meubles, protégées de l'immersion en partie par les banquettes permanentes de posidonie. Cet espace est aujourd'hui menacé par une grande pression sur les ressources halieutiques de ses eaux, mais également par des aménagements établis sur la petite Kuriat accueillant de manière non gérée d'importants flux de touristes (CAR/ASP & PNUE-PAM, 2014). Elles sont entourées de vastes herbiers de posidonie et des pelouses de *Cymodocea* (Langar *et al.*, 2011). De plus, les deux îles abritent des fonds de Maërl rares qui jouent un rôle écologique important en servant de frayère à plusieurs espèces halieutiques (Grall, 2003).

La pêche y est artisanale et côtière. L'inventaire de la faune ichtyologique a été réalisé à partir des débarquements dans les ports, des données de la Direction Générale de pêche ainsi que des questionnaires des pêcheurs (Mbarek, 2016) et sur la base de comptages visuels sous l'eau en 2008 (Ramos Espla & Ben Mustapha, 2010).

(6) Îlots nord est des îles Kerkennah, situées dans la partie Nord du golfe de Gabès en face de la ville de Sfax, ils constituent un écosystème peu étudié. Ces îlots offrent un potentiel halieutique très intéressant, notamment avec une forte productivité en poulpes *Octopus vulgaris*, en seiches *Sepia officinalis* et en Sparidae du genre *Diplodus*. Ils constituent, de loin, la principale zone de concentration des « Charfias » (pêcherie artisanale typique de cette zone pour la capture des espèces côtières) (APAL, 2010)

(7) Ile Kneiss : c'est une île dans le Golfe de Gabès, au large des côtes de la ville de Sfax. Le projet en cours de création est justifié par son importance ornithologique. Elle est connue pour abriter des colonies d'oiseaux migrateurs (APAL, 2010).

Le rôle des indicateurs dans les AMPs

Selon la Convention sur la Diversité Biologique (CDB) dont la Tunisie est signataire depuis 1977, ses sept protocoles (dont le Protocole ASP/DB) et la directive n ° 2008/56/CE du 17 Juin 2008, destinée à protéger et à restaurer les écosystèmes basés sur l'établissement d'un bon état écologique, il a été proposé d'élaborer des indicateurs pour évaluer la perte de la biodiversité. Ceci dit, pour évaluer les effets des AMPs ou de la pêche, la tendance dans le temps des indicateurs est utilisée (Trenkel & Rochet, 2003 ; Jennings, 2005). Un indicateur peut être utilisé pour établir des diagnostics et évaluer les risques relatifs aux modifications de l'écosystème (Amand *et al.*, 2004). Les indicateurs doivent présenter l'état ou la dynamique d'un système. En halieutique, les indicateurs permettent le plus souvent de mettre en évidence l'impact de la pêche et la performance des mesures de gestion. Les indicateurs à destination des gestionnaires doivent être simples et compréhensibles par des non experts. La performance de ces indicateurs se trouve principalement dans leurs propriétés statistiques et leur sensibilité à la question étudiée. Les indicateurs d'évaluation sont généralement employés pour construire des indicateurs de gestion.

Les indicateurs et les métriques sont aussi beaucoup utilisés dans le cadre de l'évaluation de l'efficacité des AMPs (Balief & Pelletier, 2011). Les indicateurs de suivi des peuplements de poissons et des pressions de pêche peuvent renseigner sur la présence ou non d'effet réserve et de bénéfice pour la pêche sur le long terme.

Problématique et objectifs de la thèse

Le recensement de la faune ichtyque en Tunisie a pour longtemps été lié à la relation directe avec l'exploitation halieutique, utilisant des techniques d'échantillonnages destructives ou en suivant directement les débarquements de la pêche (au chalut, au lampro ou artisanale), et pas avec les recensements visuels. On cite les travaux de Le Danois (1925), Azzouz (1973) sur les fonds chalutables, Bouhleb (1973) sur les Gadidae, Ben Nacer *et al.*, (2007) et Gharbi *et al.*, (2008) sur les Mullidae, Fezzani-Serbaji *et al.*, (2006) sur les chinchards, Gharred & Ktari (2001) sur les blennidae, Hattour *et al.*, (2004 ; 2005) sur les poissons pélagiques, Bradai (1990, 2005) sur les scorpaenidae, Zarrad *et al.*, (2001 ; 2004) sur le rendement des chaluts benthiques, Chemmam-Abdelkader *et al.*, (2004) et Chemmam-Abdelkader (2004) sur les denti, Fehri-Bedoui *et al.*, (2002) sur les Mugilidae, Romdhani *et al.*, (2013 ; 2014) sur les Gadidae, Fassatoui *et al.*, (2009 ; 2010 ; 2011 ; 2012) sur le pageot. L'ichtyofaune tunisienne est dominée par les Téléostéens (80 %) (Bradai, 2004). Les Elasmobranches présentent 19 % de la totalité des espèces. L'ensemble représente environ 49 % de la faune ichtyque de la Méditerranée soit 325 sur 657 (Bradai, 2004). D'après les travaux précédemment cités, les 325 espèces inventoriées se répartissent sur 221 genres, 114 familles et 30 ordres (Bradai, 2004). La spécification fait distinguer 279 espèces atlanto-méditerranéennes, 23 espèces endémiques, et 23 exotiques, certaines ayant atteint des proportions commerciales (e.g. *Siganus luridus* au Golfe de Gabès).

En Tunisie, le long des zones côtières (0-20 mètres de profondeur), le suivi des peuplements de poissons fait face à de nombreux défis :

(1) Tout d'abord, l'absence de données empiriques exhaustives sur l'assemblage de poissons «in situ » est soulignée dans plusieurs AMPs. Certains recensements ponctuels ont été effectués pour fournir des données sur les espèces vulnérables, mais n'ont pas été répliqués dans le temps.

(2) Le suivi en environnement marin, les méthodes standard de comptage de poissons requièrent beaucoup de temps et demandent une connaissance approfondie, nécessitant habituellement le recours à la plongée sous-marine pour garantir une certitude dans l'identification du poisson et une précision maximale pour l'estimation de la taille. Le manque ou l'absence de disponibilité des plongeurs scientifiques, le besoin en plongeurs formés rend plus difficile et plus coûteuse l'organisation des missions sur le terrain.

(3) Le suivi des peuplements de poissons par recensement visuel a été limité jusqu'ici aux programmes de surveillance traditionnels et ponctuels organisés dans des projets de recensement de la biodiversité dans la limite des financements disponibles.

(4) La surveillance des espèces de poissons a été effectuée en s'appuyant uniquement sur les captures de pêche dans les ports. Le suivi de la pêche côtière dans une aire géographique donnée n'a pas été fait en tenant compte de toutes les composantes et dimensions écologiques et socio-économiques, mais plutôt en focalisant sur une espèce donnée.

(5) Le cadre juridique en Tunisie de la plongée scientifique (hors clubs de plongée) n'est pas bien clair (loi de 2005)

En revanche, la plongée récréative dans le cadre des clubs de plongée est une activité en développement dans de nombreuses villes. On recense 300 plongeurs récréatifs pratiquants appartenant à 12 clubs de plongées répartis le long des côtes tunisiennes (Fédération des Activités Subaquatiques Tunisiennes FAST, 2017). Cela présente un potentiel à explorer pour le monitoring des ressources marines en général et des peuplements de poissons en particulier sur toutes les côtes et dans les futures AMPs tunisiennes en particulier. Ainsi, le choix des méthodes appropriées pour le suivi des assemblages des poissons et des pressions de pêche dans une AMP donnée est une étape importante, d'autant plus quand il s'agit d'un futur réseau d'AMPs.

Le développement de ce réseau d'AMPs s'accompagne d'un besoin d'outils d'évaluation de la performance des AMPs et des pressions de pêche. Il apparaît primordial pour les AMPs ou AMCPs de la Tunisie de connaître et de suivre les activités présentes sur leur territoire ainsi que leur dynamique, afin d'en évaluer les pressions et les impacts, mais aussi leur réponse aux mesures

de gestion mises en place. Ainsi, la création d'AMPs s'accompagne de suivis scientifiques des ressources biotiques et abiotiques, en particulier ceux qui sont sujets aux objectifs de l'AMP.

L'objectif principal de notre travail est de proposer, tester, adapter et ajuster des méthodes et des indicateurs pour le suivi des peuplements de poissons et de la pêche le long des futures AMPs tunisiennes (Tabarka, Cap Negro-Cap Serrat, l'archipel de Zembra et les îles Kuriat). Ainsi, pour notre travail, en plus du suivi des peuplements de poissons par recensement visuel, nous testons 3 autres méthodes de suivi de la pression de pêche :

- (1) Transects de largeurs variables (TVW)
- (2) Fish Assemblage Sampling Technique (FAST)
- (3) Questionnaires socio-économiques à tous les pêcheurs côtiers dans les futures AMPs d'étude. Cela permettrait d'avoir une vue d'ensemble de la pression exercée, de l'activité, des techniques, et de la motivation pour pêcher (artisanale, récréative, autres...)
- (4) Pêche expérimentale avec les pêcheurs artisanaux, pour recueillir des données « avant impact » en utilisant le même engin que les pêcheurs, où la pêche artisanale sera probablement autorisée.
- (5) Méthode de suivi de la fréquentation, en utilisant la méthode de la photo-surveillance.

Ainsi, dans le cadre de l'objectif global de cette thèse et à partir des différentes méthodes appliquées, différentes hypothèses ont été testées, selon 5 sous/objectifs (chaque sous-objectif correspond à un chapitre) :

S/objectif 1 : revue bibliographique des méthodes, métriques et indicateurs de suivi des peuplements de poisson et de la pêche.

S/objectif 2 : démarrer un design expérimental avant impact pour trois futures AMPs en utilisant la méthode standard UVC

Hypothèse 1. Existe-t-il une différence significative entre l'intérieur (future zone protégée) et l'extérieur (zone non protégée) dans les mesures d'assemblage de poissons (densité, biomasse et distribution de taille) ?

S/objectif 3 : Face au manque de données dans les zones côtières et au manque de plongeurs scientifiques, proposer et tester une méthode facile à utiliser en collaboration avec les plongeurs bénévoles

Hypothèse 2. La méthode UVC standard est-elle comparable à la méthode UVC facile à utiliser (FAST) ?

Hypothèse 3. Les résultats des bénévoles formés scientifiquement (STV) sont-ils significativement différents des plongeurs scientifiques (SD) ?

S/objectif 4 : faire face à la pression de la pêche côtière : comprendre à la fois les caractéristiques écologiques et socio-économiques de la pêche côtière en Tunisie

Hypothèse 4. Utilisation de questionnaires et suivi des débarquements : Existe-t-il une différence significative entre les catégories de pêche côtière (commerciale à petite échelle, récréative et illégale) en utilisant la capture moyenne, le niveau trophique moyen (MTL), l'indice de vulnérabilité intrinsèque (IVI) et le prix moyen des captures (MCP) ?

Hypothèse 5. Utilisation de la méthode de pêche expérimentale : Existe-t-il une différence significative entre l'intérieur (future zone protégée) et l'extérieur (zone non protégée) dans les mesures de pêche artisanale (biomasse, richesse en espèces, proportion de grande taille (LP) et proportion de carnivores (CP)) ?

S/objectif 5 : tester la méthode de la photo-surveillance

*Chapter II: Methods, metrics and
indicators of fish assemblages
and fishing activities
monitoring in MPAs*

II.1. Abstract

Tunisia is a country where coastal zones are undergoing a lot of pressures but where biodiversity is with high levels. To protect resources and put in place sustainable development of activities, since the year 1998, there is a strategy to implement a network of MPAs along coastal zones. MPAs creation comes with the need of a monitoring strategy for resources especially for fish assemblages that are the first mean to evaluate MPA effectiveness. Thus, at this stage, the objective of our work is to review methods and their outputs (in terms of metrics and indicators) related to the purpose of detecting changes in fish assemblages under fishing pressure or protection in MPAs. Overall, individual size method assesment contributed to 33% while presence/absence methods and sampling with catch of fish presented 9% and 6% respectively. Metrics and indicators that contributed the most to the assesment of fish assemblage are: (1) biomass, (2) density, (3) Species Richness and (4) size distribution frequency. Concerning fishing activities, the most used metrics/indicators in the checked literature were: (1) size spectra/body size, (2) Catch Per Unit Effort (CPUE)/ mean catch, (3) Mean Trophic Level (MTL) and (4) Maximum Sustainable Yield (MSY). According to classification of metrics and indicators, nine were chosen fo Tunisian future MPAs: (1) FAST indicators, (2) Species richness, (3) Density, (4) Biomass, (5) size frequency distribution, (6) Mean Catch, (7) vulnerable species, (8) Mean Trophic Level of the catch (MTL), and (9) Intrinsic vulnerability of the catch. The rationale behind the present review is to determine methods, metrics and indicators that are suitable for fish assemblage and fishing monitoring, which can be useful for managers in Tunisian future MPAs.

II.2. Introduction

When it comes to human pressure on the environment, primary driving forces are population growth and economic activities needed by individuals. These primary driving forces provoke changes in the overall levels of production and consumption, which increases the exerted pressure on the environment.

We use methods to assess environment metrics (e.g. biological, ecological, performance of management measures). Methods outputs should be concrete and simplify the complex reality (Smeets and Weterings, 1999). Data collected can be quantitative (mathematical) or qualitative.

Quantitative data can be variables, metrics, indices or indicators. In the literature, a given variable may have been used at several scales, e.g. density per species, density of species group or total density of fish community. A variable measured at a given level is termed as a “metric”. A metric constitutes a potential indicator for one or for several effect-related to a given factor (e.g. protection of a coastal area, pollution, exploitation) (Pelletier *et al.*, 2008). Variables, metrics and indicators can be defined as follows:

Variable: A characteristic, number, or quantity that increases or decreases over time, or takes different values in different situations. Two basic types are (1) Independent variable: that can take different values and can cause corresponding changes in other variables, and (2) Dependent variable: that can take different values only in response to an independent variable (Pelletier *et al.*, 2008).

Metric: Standards of measurement by which efficiency, performance, progress, or quality of a plan, process, or product can be assessed. Metrics common to all models are total catch, total abundance and total biomass (Pelletier *et al.*, 2008)

Indicator, Index: It is a measurable variable used as a representation of an associated (but non-measurable) factor. An indicator may be qualitative or quantitative variable that can be obtained from field surveys or from models, and that can be directly linked to a management objective or a research question (Pelletier *et al.*, 2008). For instance, it represents an integrated part in fisheries management (Rogers and Greenaway, 2005).

We distinguish three types of environmental descriptive indicators: (1) Pressure indicators, (2) state indicators, and (3) Impact indicators (Pelletier *et al.*, 2005). All three types can be direct or indirect descriptors (Pelletier *et al.*, 2008). In relation to policy making, environmental indicators are used for many purposes. For instance, they supply information on environmental problems, support policy development and priority setting and monitor the effects of policy responses. Many existing indicators describing different components or set of components in the ecosystem, such as fish assemblage, and each of which may provide a specific type of information to answer a specific

question. Many classifications of these indicators exist, ranging from their organization level to their properties (Rice, 2000), nature (Link *et al.*, 2002) or ecosystem objectives (Gislason *et al.*, 2003).

In this context, monitoring of marine resources in coastal areas, and in marine protected areas specifically, is a key to reliable information. In several Mediterranean MPAs, scientific monitoring was performed at different levels using different metrics to detect reserve effect on fish assemblages (e.g. Dufour *et al.*, 2007; Guidetti *et al.*, 2008; Edgar *et al.*, 2014; Seytre & Francour, 2014). Hence, many authors highlighted the necessity of getting “Before Impact” data, i.e. before MPA implementation to have a solid basis to compare with the “After Impact” data.

In Tunisia (South Mediterranean coasts), since the year 1998, there is a national strategy to protect “vulnerable coastal zones” and to implement a MPAs network (APAL, 2010). Therefore, monitoring strategies should be set up to get data before and after “impact” i.e. protection. Monitoring strategies should respond to MPAs objectives (e.g. fish assemblage monitoring, vulnerable species; Commercial Small Scale (CSS) fisheries, recreational fishing, effect of tourism and recreational diving, etc.). Thus, within this review, we are interested to methods, metrics and indicators aiming at testing hypotheses about fish assemblage conservation and fisheries-related effects of MPAs. At a first place, we review methods outputs (in terms of metrics and indicators) related to the purpose of detecting changes in fish assemblages under fishing pressure or protection in MPAs.

So, methods were divided into two groups, (A) underwater monitoring of fish assemblages (using UVC techniques) and (B) monitoring of fishing activities. Then, we discuss and evaluate metrics and indicators from the literature following a set of criteria: (1) concreteness, (2) measurability, (3) sensitivity, (4) specificity, (5) applicability, (6) theoretical basis, (7) scale dependency, (8) cost, (9) availability of historical data, and (10) public awareness. The rationale behind our review is to provide guidelines and summaries for fish assemblage monitoring, which can be useful for managers in MPAs.

II.3. Method and indicators choice

In all, 283 references dealing with fish assemblage monitoring in Mediterranean coastal zones and in MPAs were used to select methods, metrics and indicators.

II.3.1. Methods challenges

For marine and coastal fish communities, a variety of monitoring methods exist. Estimation of metrics can vary with the survey method selected, influencing both the precision and accuracy of the data (Côté & Perrow, 2006). Given that survey results may be used for conservation and management decisions, it is therefore important to evaluate how different monitoring methods perform, and whether they can replace or complement each other (Murphy & Jenkins, 2010, Baker *et al.*, 2016). In most MPAs all over the world, scientists monitored fish assemblages using underwater visual census (UVC) inside no-take zones (e.g. Sala *et al.*, 2012; Edgar *et al.*, 2014; Aburto-Oropeza *et al.*, 2015), monitoring of fishing effort and catches (e.g. Batista *et al.*, 2015) and experimental fishing (e.g. Seytre *et al.*, 2013). Monitoring fish assemblages using visual census methods in Tunisian future MPAs is facing many challenges. Firstly, funds are highly determinant in monitoring programs. Then, fish monitoring using standard UVC methods needs highly skilled divers in species identification and a lot of training and calibrations dives (Prato *et al.*, 2016).

Moreover, in data poor regions, institutional and research monitoring programs are usually punctual in space and time scales. This is the case for monitoring fish assemblages in Tunisian future MPAs, where abundance data were recorded by scientists to provide, in most of the cases, data for management plans for MPAs. These inventories used UVC methods, mainly along transects (e.g. Harmelin *et al.*, 2010; Ody *et al.*, 2010, Ramos Espla *et al.*, 2008). More replicated monitoring programs are needed in future MPAs. To do so, volunteer based monitoring programs (Citizen Science) are perceived as a cost-effective way to gather data efficiently in data poor regions. Thus, in understudied contexts, all information gathered are needed and can be useful. A minimum of resources can be used to collect a minimum but an essential amount of data, such as monitoring target fish. Then, as resources available for the monitoring increases, the data collected is more complete and exhaustive (Figure II-1). Methods used for assessing protection effect and fishing

pressure were mainly underwater visual census techniques, monitoring of fishing landings and socio-economic questionnaires.

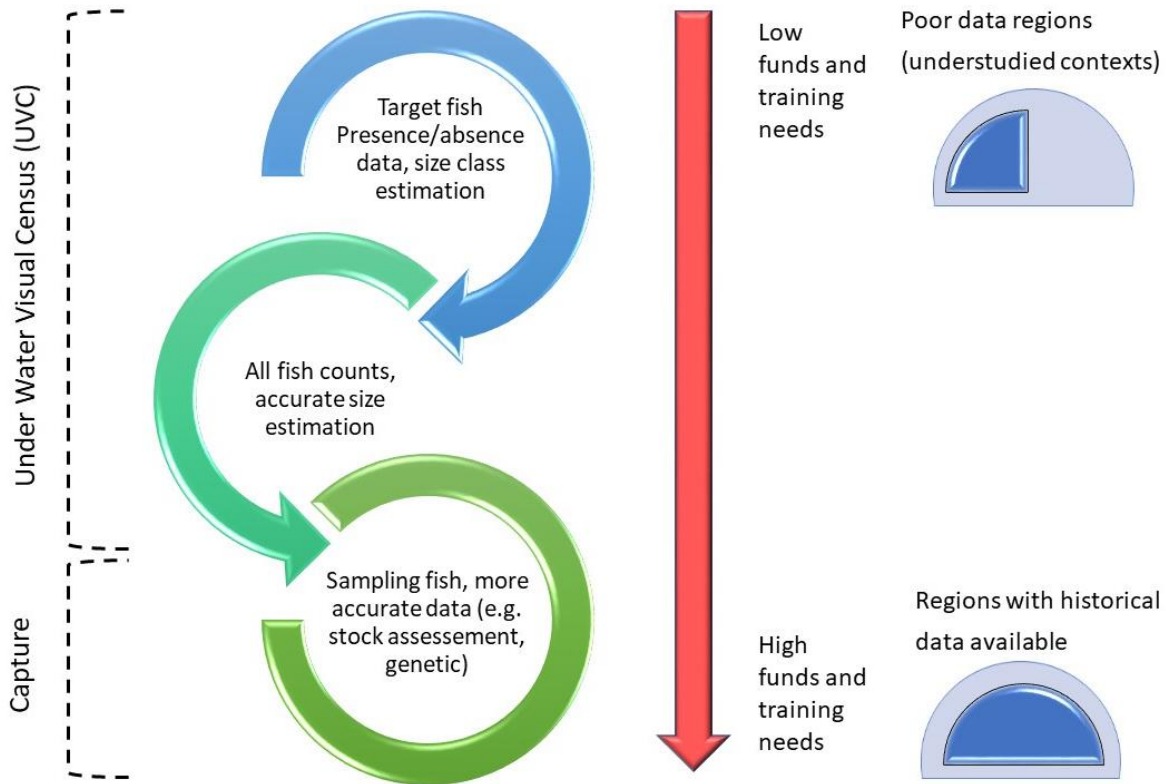


Figure II.5. Summary of fish assemblage monitoring characteristics according to funds, training needs and historical data availability

II.3.2. Metrics and indicators choice

Much of the peer-reviewed literature relating to evaluating management effectiveness of MPAs addresses how to set management objectives and select indicators to assess MPA effects (e.g. Beliaeff & Pelletier, 2011; Pelletier *et al.*, 2005). There is a great need for prescriptive discussion about how to set quantitative targets and use these to assess the effectiveness of marine protection (e.g. Samhuri *et al.*, 2012).

We used a set of criteria to differentiate and classify metrics and indicators. The aim of this classification is to have a clear set of metrics and indicators per monitoring purpose and per method used. It is expected that, following our reasoning, a manager could choose according to his

monitoring needs, what method to apply and what output he will get. Criteria chosen for classification are the following:

1/ concreteness: A concrete indicator is specific, real and tangible. If it constitutes a concrete description of the physical/biological properties (Rice & Rochet, 2005), we classify it as with high concreteness (H). In contrast, if it is an abstract concept, it is considered as with low one. This criterion is directly related to the monitoring objective (i.e. effect of protection, effect of fishing, effect of feeding fish when diving...). The evaluation of each metric was derived from the existing literature.

2/ measurability: if the indicator is measurable from empirical approach or not. In response to the question “can the variance and bias of the indicator be estimated?”: If “yes”, the metric is considered as measurable (M) and if “no”, it is not measurable (NM).

3/ Sensitivity or responsiveness: is the response to the factor to which it is related. In MPA contexts. Thus, an indicator that could changes value within 1-5 years of implementation of management measures is considered as with high sensitivity (H) while if it will only reflect system responses to management on decadal scales or longer, it is considered as with low (L) sensitivity.

4/ specificity or exclusiveness: in response to the question: Is the impact of the stressors on the indicator systematic and known (high, H) or irregular or poorly understood (low, L)?

5/ Applicability of the method (difficulties): If the person who will do the sampling need a lot of training and calibrations (difficult D) to get used to a given method or not (E).

6/ theoretical basis: if the indicator has been derived from direct empirical observations (High), or from interpretation through model (Low). Information was used from literature.

7/ Scale dependency

Empirical approaches are strongly hampered by observation scale. Most studies relying on UVC or experimental fishing, are conducted locally and provide snapshot observations. These data enable observing every species and estimating metrics at community level (Pelletier *et al.*, 2008). We

classify metrics and indicators according to the biotic scale (species or community), following the existing literature.

8/ cost: There is no general rule to assess the cost of the data collection or the empirical indicators. The cost of gathering the information needed for calculating empirical indicators depends on the precision required for the sampling scheme, which in turn depends on the scale of the effect to be detected, on sample size, and on the sensitivity of the sampling method and thus of the indicator to this effect (the relevance of the indicator) (Nicholson & Fryer, 2002). If a given set of information may be used to estimate several indicators, it will thereby result in decreased costs per indicator. For instance, fish density, biomass, and mean size may be estimated from the same set of UVC data. We consider high cost indicators (H) as the one that are calculated from expensive sampling methods and from taking (scarifying) the fish only for the purposes of the sampling. While others are considered as with low (L) cost. Description of indicators following this criterion is made from the existing literature and from estimations for Tunisian contexts.

9/ availability of historical data: to allow comparisons with previous status: Necessary data are available for: periods of several decades (High), to only relatively recent period (moderate), to opportunistic or none available (Low).

10/ Public awareness: in response to the question: “Does public understands to what correspond with the technical meaning of indicator?”: If well, it is considered as with high (H) public awareness, if poorly, it is with low (L) one. This criterion is very important for communicating results of scientific monitoring in MPAs and try to raise awareness in public for the co-management strategies needs.

II.4. Set of indicators

We divide metrics and indicators into two groups, basing on the method used to get correspondent data:

(A) *Monitoring of fish assemblages underwater (using UVC techniques) (Figures II.2 and II.3, Table II.1 and supplementary material II.1).*

There is a set of methods used by scientists to perform UVC (e.g. stationary points, standardized transects, transects with variable width, FAST method, using video...etc). Here, we used a simple criterion to classify metrics and indicators which is the difficulty of UVC method: (1) data collected using a presence/ absence method, (2) data collected using counts of each species and individuals, (3) data collected using counts and size estimation or (4) data collected by fish sampling.

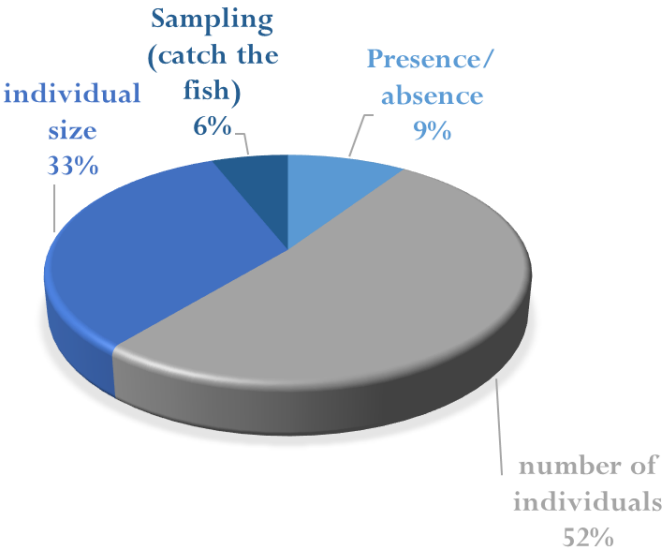


Figure II.2. Distribution (in percentage) of metrics and indicators according to assesment method (percentage are calculated on a total of 147 published paper).

Overall, metrics and indicators calculated from number of individuals counts were assessed at 52% of the total investigated papers. Individual size method assesment contributed to 33% while Presence/absence methods and assesment with catch of fish presented 9% and 6% respectively (Figure II.2). More precisely (Figure II.3) metrics and indicators that contributed the most to the assesment of fish assemblage are: (1) biomass (per species, per family, per trophic category), used at 25.17%, (2) density at 22.44%, (3) Species Richness at 10.88% and (4) size distribution frequency or body size at 5.44% of total checked papers.

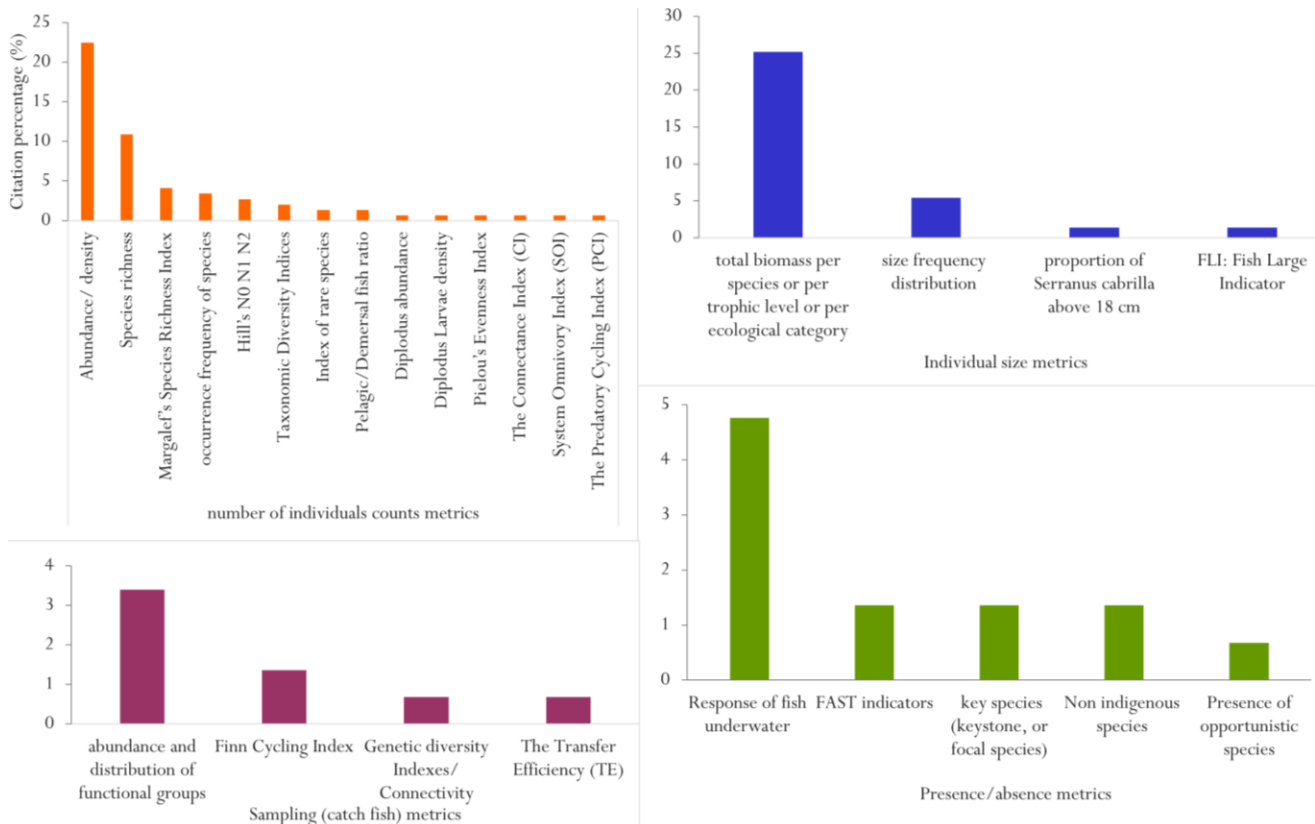


Figure II.3: Percentage of citation of metrics and indicators per assesment method

According to the classification made for each metric and indicator (see Table II.1), five metrics were chosen to assess fish assemblages in selected Tunisian MPAs. The choice was made following criteria of concreteness (High), measurability (Measurable), sensitivity to ‘reserve effect’ and fishing pressure (High). For the other criteria, metrics chosen were applicable by all stakeholders or not, to the scale of species or assemblage, specific or not, with low or high public awareness. It was important to propose for the Tunisian context, methods, metrics and indicators that can applied by scientists or not. Therefore, indicators that were chosen are: (1) FAST indicators, (2) Species richness, (3) Abundance or density at different levels (total and trophic categories), (4) Biomass at different levels, and (5) size frequency distribution.

Table II.1. Classification of metrics and indicators according to concreteness (h: high, L: low), measurability (M: measurable; N: non measurable), Sensitivity to the expected effect (H: high, l: Low), Specificity to the factor (H: high, L: low), Applicability by fisherman, recreational, volunteer divers or MPA managers, (D: difficult, E: easy); theoretical basis (H: high, L: low), Scale

(A: assemblage, S: species), cost (H: high, L: low), Availability of historical data (NA: not available, A: available) and Public awareness (H: high, L: low)

N°	metric	Concreteness	Measurability	Sensitivity	Specificity	Applicability by				Theoretical basis	Scale	Cost	Availability of historical data	Public awareness
						Fisherman	Recreative	Volunteer	Manager					
1	FAST indicators	H	M	H	H	D	E	E	E	H	A	L	NA	L
2	key species (keystone, indicators) ou focal species	H	M	H	H	E	D	E	E	H	S	L	NA	H
3	Non indigenous species	H	M	L	L	E	E	E	E	H	S	L	NA	H
4	Presence of opportunistic species	H	M	L	L	D	D	D	D	H	S	L	NA	L
5	Response of fish underwater (positive or negative)	L	N	L	H	D	E	E	E	L	S	L	NA	L
6	Species richness	H	M	L	L	D	D	E	E	H	A	L	NA	L

Table II-1. Continuity

N°	metric	Concretness	Measurability	Sensitivity	Specificity	Applicability by				Theoretical basis	Scale	Cost	Availability of historical data	Public awareness
						Fisherman	Recreative	Volunteer	Manager					
7	Margalef's Species Richness Index	L	N	L	L	D	D	D	D	H	A	L	NA	L
8	occurrence frequency of species	H	M	L	L	E	E	E	E	H	A/S	L	NA	L
9	Abundance	H	M	H	L	E	E	E	E	H	A/S	L	NA	H
10	density per ecological category	H	M	H	L	D	D	E	E	H	A	L	NA	L
11	Diplodus abundance	H	M	H	L	E	E	E	E	H	S	L	NA	L
12	Density (adult)	H	M	H	L	E	E	E	E	H	A/S	L	NA	H
13	Diplodus Larvae density	H	M	H	L	D	D	D	D	H	S	H	NA	L

Table II-1. Continuity

N°	metric	Concretness	Measurability	Sensitivity	Specificity	Applicability by				Theoretical basis	Scale	Cost	Availability of historical data	Public awarness
						Fisherman	Recreative	Volunteer	Manager					
14	Hill's No N1 N2	L	N	L	L	D	D	D	D	H	A	L	NA	L
15	Pielou's Evenness Index	L	N	L	L	D	D	D	D	H	A	H	NA	L
16	Margalef's Species Richness Index	L	N	L	L	D	D	D	D	H	A	H	NA	L
17	The Connectanc e Index (CI)	L	N	L	L	D	D	D	D	H	A	H	NA	L
18	System Omnivory Index (SOI)	L	N	L	L	D	D	D	D	H	A	H	NA	L
19	The Predatory Cycling Index (PCI);	L	N	L	L	D	D	D	D	H	A	H	NA	L

Table II-1. Continuity

N°	metric	Concretness	Measurability	Sensitivity	Specificity	Applicability by				Theoretical basis	Scale	Cost	Availability of historical data	Public awarness
						Fisherman	Recreative	Volunteer	Manager					
20	Shannon index based on weigh or on abundance	L	N	L	L	D	D	D	D	H	A	H	NA	L
21	Taxonomic Diversity Indices	L	N	L	L	D	D	D	D	H	A	H	NA	L
22	Pelagic/Demersal fish ratio	H	M	L	L	D	D	D	D	H	A	L	NA	L
23	total biomass	H	M	H	H	D	D	D	D	H	A/S	L	NA	L
24	size frequency distribution	H	M	H	H	D	D	D	D	H	A/S	L	NA	H
25	proportion of Serranus cabrilla above 18 cm	H	M	L	L	E	E	E	E	H	S	L	NA	L

Table II-1. Continuity

N°	metric	Concretness	Measurability	Sensitivity	Specificity	Applicability by				Theoretical basis	Scale	Cost	Availability of historical data	Public awarness
						Fisherman	Recreative	Volunteer	Manager					
26	FLI: Fish Large Indicator	H	M	H	H	D	D	D	D	H	A/S	L	NA	L
27	Genetic diversity Indexes	H	M	L	L	D	D	D	D	H	A/S	H	NA	L
28	Finn Cycling Index	L	N	L	L	D	D	D	D	H	A	H	NA	L
29	The Transfer Efficiency (TE);	L	N	L	L	D	D	D	D	H	A	H	NA	L

(B) Monitoring of fishing activities (Figures II.4 and II.5, Table II.2 and Supplementary Material II.2)

Many methods are in use to monitor fishing activities, e.g. using socio-economic questionnaires, monitoring of landed catch, experimental fishing, monitoring of MPAs frequentation using human resources or technology (for instance video or photo-surveillance).

The most used metrics/ indicators in the checked literature (116 references) were: (1) size spectra/body size (22.55%), (2) Catch Per Unit Effort (CPUE)/ mean catch (19.82%), (3) Mean Trophic Level (MTL) (10.34%) and (4) Maximum Sustainable Yield (MSY) (8.62%).

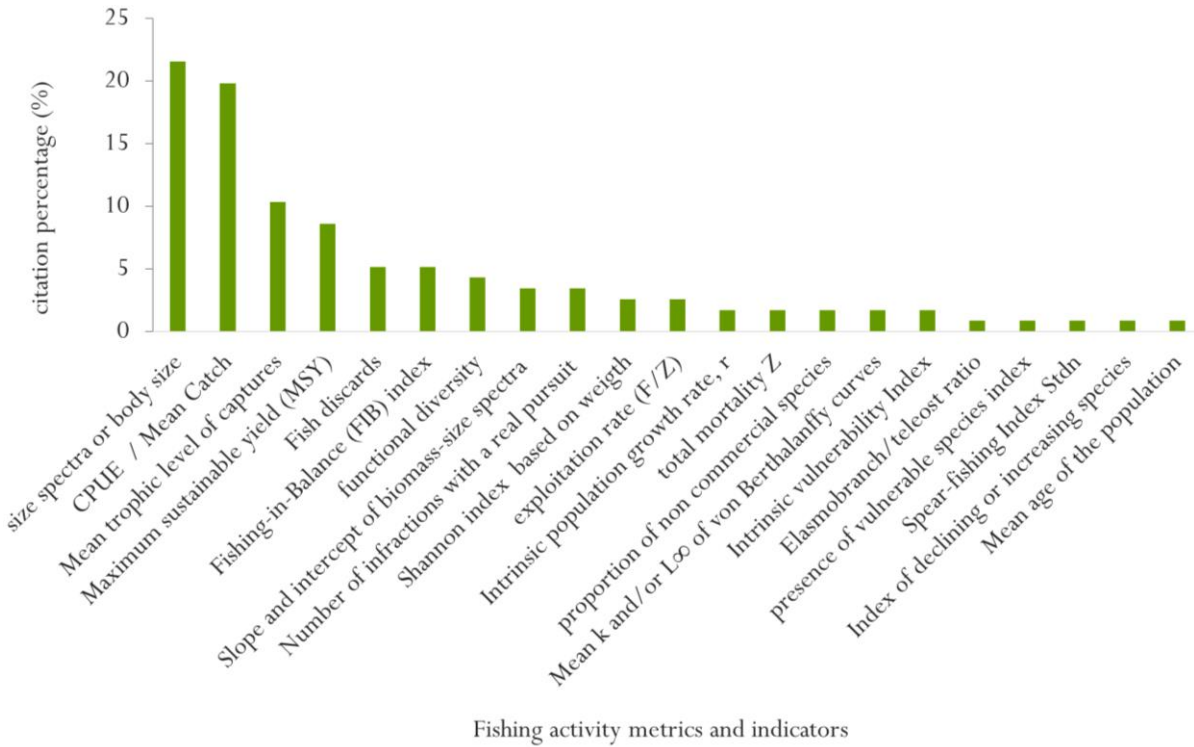


Figure II.4. Distribution (in percentage) of metrics and indicators to assess fishing activities (percentage are calculated on a total of 116 published paper). Some metrics/indicators were grouped to avoid repetitions.

According to the classification made for each metric and indicator (see Table II.2), five metrics were chosen to assess fishing activities in selected Tunisian MPAs, using questionnaires and landed catch monitoring. The choice was made following criteria of concreteness (High), measurability (Measurable), sensitivity to 'reserve effect' and fishing pressure (High). For the other criteria, metrics chosen were applicable by all stakeholders or not, to the scale of species or assemblage, specific or not, with low or high public awareness. It was important to propose for the Tunisian context, methods, metrics and indicators that can be applied by both scientists and other stakeholders. Therefore, indicators that were chosen are: (1) Mean Catch, (2) Species richness and vulnerable species, (3) Size class distribution, (4) Mean Trophic Level of the catch (MTL), and (5) Intrinsic vulnerability of the catch.

Table II.2. Classification of metrics and indicators according to concreteness (h: high, L: low), measurability (M: measurable; N: non measurable, Sensitivity to the expected effect (H: high, l: Low), Specificity to the factor (H: high, L: low), Applicability by fisherman, recreational, volunteer divers or MPA managers, (D: difficult, E: easy); theoretical basis (H: high, L: low), Scale (A: assemblage, S: species), cost (H: high, L: low), Availability of historical data (NA: not available, A: available) and Public awareness (H: high, L: low)

Nº	Metric	Concrete ss	Measurabil ity	Sensitivi ty	Specific ity	Applicability by				Theoreti cal basis	Scal e	Cos t	Availabil ity of historical	Public awarnes s
						Fisherm an	Recreat ive	Volunte er	Manage r					
1	CPUE per species and per trophic level / Mean catch	H	M	H	H	D	D	D	D	H	S/A	L	A*	L
2	biomass of fish discarded	H	M	L	L	E	E	E	E	L	S/A	L	NA	L
3	Distribution of functional groups,	H	M	L	H	D	D	D	D	H	S/A	H	NA	L
4	Elasmobranch/teleo st ratio	H	M	L	L	E	E	E	E	L	A	L	A*	L
5	presence of vulnerable species	H	M	H	H	E	E	E	E	H	S	L	A*	H
6	Abundance Biomass Comparison Index ABC index	H	M	L	H	D	D	D	E	H	A	L	NA	L
7	Shannon index based on weighth	H	M	L	L	D	D	D	D	H	A	H	NA	L

Table II-2. Continuity

N°	Metric	Concrete	Measurability	Sensitivity	Specificity	Applicability				Theoretical basis	Scale	Cost	Availability of historical data	Public awareness
						Fisherman	Recreative	Volunteer	Manager					
8	Fishing-in-Balance (FIB) index	L	N	L	L	D	D	D	D	L	A	H	NA	L
9	Intrinsic population growth rate, r	H	N	L	L	D	D	D	D	H	A	H	A*	L
10	exploitation rate (F/Z)	H	N	L	L	D	D	D	D	H	S/A	H	A*	L
11	total mortality Z	H	N	L	L	D	D	D	D	H	S/A	H	A*	L
12	proportion of non commercial species	H	M	H	L	E	E	E	E	L	S/A	L	NA	L
13	Spear-fishing Index Stdn	H	M	H	H	E	E	E	E	L	A	L	NA	L
14	Maximum sustainable yield (MSY)	L	N	L	L	D	D	D	E	H	S	H	A	L
15	Index of declining or increasing species	H	M	H	L	D	D	D	E	H	S/A	L	NA	H

Table II-2. Continuity

Nº	Metric	Concrete ness	Measurabil ity	Sensitivi ty	Specific ity	Applicability				Theoreti cal basis	Scal e	Cos t	Availabil ity of historical data	Public awarnes s
						Fisherm an	Recreat ive	Volunte er	Manage r					
16	Mean k and/or L∞ of von Berthalanffy growth curve	L	N	L	L	D	D	D	D	H	S/A	H	A	L
17	body size or size spectra (min and max size)	H	M	H	H	E	E	E	E	H	S/A	L	NA	H
18	Slope and intercept of biomass-size spectra	H	M	H	H	D	D	D	D	H	S/A	H	NA	L
19	Mean trophic level of catch	H	M	H	H	D	D	D	D	H	A	L	A	L
20	Intrinsic vulnerability of the catch	H	M	H	H	D	D	E	E	H	S/A	L	NA	L
21	Mean age of the population	H	N	L	H	D	D	D	D	H	A	H	A*	L
22	Number of infractions with a real pursuit	H	M	ND	H	D	D	E	E	H		L	A*	H

II.5. Discussion

The used criteria to classify metrics and indicators (Tables II.1 and II.2) was based on the practical aspect. A global view of used methods, metrics and indicators, their relevance, applicability and costs, is necessary to determine which most relevant metrics and indicators to calculate for fish assemblages and fishing activities monitoring. This review can be very useful at this stage of before creating Tunisian MPAs.

Method used should not be destructive. So, fish assemblage monitoring using UVC techniques, the most exhaustive techniques (transects) should be applied to gather density, biomass, and size frequency distribution that are metrics mostly used in literature to assess the reserve effect in other Mediterranean MPAs. Other easy-to-use UVC methods can be used also to assess underwater fish assemblage variability using these standard methods, it is also possible to use, more often, presence/absence monitoring techniques, such as Fish Assemblage Sampling Technique FAST.

Metrics and indicators calculated can be also informative about target fish by professional or non-professional fishing. Even though outputs of presence/absence monitoring are not as exhaustive as the standard UVC ones, they have the advantage of being easy-to-use which allow their applicability by managers, volunteer divers and other MPAs users. The fact of involving volunteers in scientific monitoring (citizen science programs) using easy-to-use methods is cost-effective since volunteers usually dive for their own pleasure and often supply their own diving equipment. Scientific training to methods applications, fish identification and use of outputs can also be of great use to spread awareness about MPAs and scientific monitoring use. Therefore, using transects with variable width and FAST methods, indicators that will be calculated are: (1) FAST indicators, (2) Species richness, (3) Abundance or density at different levels (total and trophic categories), (4) Biomass at different levels, and (5) size frequency distribution.

Tunisian future MPAs are being created to protect resources and to enhance socio-economic activities such as artisanal fishing. Usually, for fish assemblage monitoring, destructive method should not be applied in protected areas, but since commercial small-scale fishing will be permitted in some zones, it is important to monitor fishing practiced using frequentation surveys, socio-economic questionnaires and catch monitoring, or experimental fishing. These methods allow (1) to monitor fishing activities, (2) to determine actors in protected areas (fishing types) and (3) to get a close idea about fishing efficiency, species caught and other metrics and indicators calculated as outputs. Therefore, indicators that were chosen are: (1) Mean Catch, (2) Species richness and vulnerable species, (3) Size class distribution, (4) Mean Trophic Level of the catch (MTL), and (5) Intrinsic vulnerability of the catch. An additional metric was proposed is the Mean Catch Price, calculated as the average economical value of the catch.

Supplementary material II.1. Fish Assemblages metrics and indicators split on data collection basis, with correspondent references, advantages and limits (metrics in colors are those that will be used for the Tunisian context)

method	N°	metric	References	advantages	Difficulties	observations
Presence/absence	1	FAST indicators	Seytre et al., 2008; 2009	gives rapidly an idea about changes in fish assemblages under fishing pressure, does not need a heavy training for scientific or volunteers	does not give a quantitative precision about density and biomass,	
	2	key species (keystone, or focal species)	Daan, 2001; Piet & Pranovi, 2005	species are usually monitored in the same time with other assemblage species. These species as HTLP are easily identified.		
	3	Non indigenous species	Gravili <i>et al.</i> , 2010; Bodilis <i>et al.</i> , 2014	informs about the structure of fish assemblage and the percentage of indigenous species comparing to the NIS	needs a knowledge of non indigenous species and a large communication about it	
	4	Presence of opportunistic species	Piet & Pranovi, 2005	defined as species that follow the reproductive r-strategy, with short life-cycle (<1 year), small size, rapid growth, early sexual maturity.	fish species opportunistic are not well-defined, need well knowledge and communication	
	5	Response of fish underwater	Guidetti <i>et al.</i> 2014, Rochet & Trenkel, 2003 ; Pelletier <i>et al.</i> , 2008; Piet <i>et al.</i> , 2008 ; Bellail <i>et al.</i> , 2003; Gascuel & Hénichart., 2011 ; Nicholson & jennings, 2004	estimation of the response of fish	important bias due to observer effect and the appreciation of the escape response by the divers, conceptual	
number of individuals	6	Species richness	e.g. Rochet <i>et al.</i> , 2005 ; Russ & Alcala, 1996 ; Piet <i>et al.</i> , 2011 ; Seytre & Francour, 2013 ; Fenberg <i>et al.</i> , 2012 ; Higdón <i>et al.</i> , 2013 ; Mouillot <i>et al.</i> , 2005; Pelletier <i>et al.</i> , 2008 Piet et al., 2008; Sahyoun <i>et al.</i> , 2013; adams & Greely, 2000; Gascuel & Hénichart., 2011 Nicholson & jennings, 2004; Pelletier <i>et al.</i> 2012; Stamoulis & Friedlander, 2013, Guidetti et Bussotti, 2000			
	7	Margalef's Species Richness Index	Coeck et al. 1993, Penczak & Kruk 1999 In Aguilar Ibarra, 2004; Agard et al., 1993; Warwick and Clarke, 1994; Piet and Pranovi, 2005; Clarke and Warwick, 2001	this index provides an alternative solution to an index of species richness that takes account of variation in sampling effort.		Margalef's index, calculated as= $(S - 1) \ln(N)$

Table II-1. Continuity

Method	N°	Metric	References	Advantages	Difficulties	Observations
number of individuals	8	occurrence frequency of species	Bussotti & Guidetti, 2009; Bussotti <i>et al.</i> 2015 ; Tessier <i>et al.</i> , 2011; Lae <i>et al.</i> 2004; Seytre & Francour, 2008; 2009	a relative idea about the presence of a species, informative		
	9	Abundance	e.g. Bourquard, 1985; Russ & Alcalá, 1996; Piet <i>et al.</i> , 2012 ; Gascuel <i>et al.</i> , 2007 ; Bellail <i>et al.</i> , 2002 ; Piet <i>et al.</i> , 2009 ; Guidetti, 2007 ; Guidetti, 2006 ; Thia & Mbaye, 2012 ; Pelletier <i>et al.</i> , 2008; Piet <i>et al.</i> , 2008 ; Fenberg <i>et al.</i> , 2012; Guidetti, 2006 ; adams & Greely, 2000; Bellail <i>et al.</i> , 2003; Gascuel & Hénichart., 2011 ; Nicholson & Jennings, 2004; Rochet <i>et al.</i> , 2005; Pelletier <i>et al.</i> 2012; Stamoulis & Friedlander,	shows the number of individuals of species in an assemblage	is not very very precise because high values of abundance does not mean high values of species or indicator species (case of Chromis chromis or fish in shoals as Sardinella or Spicara)	
	10	<i>Diplodus</i> abundance	Guidetti, 2006	specific and precise to assess protection effect on <i>Diplodus</i> and sea urchins density,	it is to be applied only by scientists, heavy sampling	
	11	Density	Hueckel <i>et al.</i> , 1989; Guidetti & Bussotti, 2001 ; Russ & Alcalá, 1998 ; Di Franco <i>et al.</i> , 2013 (b); Bussotti & Guidetti, 2008; Tessier <i>et al.</i> , 2011; Piet <i>et al.</i> , 2008; Fenberg <i>et al.</i> , 2012; Guidetti & Bussotti, 2000; Di Franco <i>et al.</i> , 2013 ; Sahyoun <i>et al.</i> , 2013; Pelletier <i>et al.</i> 2012; Stamoulis & Friedlander, 2013	synonym of the abundance, basis indicator, shows the number of individuals of species in an assemblage	is not very very precise because high values of abundance does not mean high values of species or indicator species (case of Chromis chromis or fish in bands as Sardinella or Spicara)	
	12	<i>Diplodus</i> Larvae density	Di Franco <i>et al.</i> , 2013	very specific to <i>Diplodus</i> stocks	destructive when sampling juvenile	

Table II-1. Continuity

Method	N ^o	metric	References	Advantages	Difficulties	Observations
number of individuals	13	Index of rare species	Daan 2001; Piet & Pranovi, 2005	variability in abundance of the uncommon species in a survey can illustrate underlying patterns of change that are not evident from analysis of the dominant parts of the		
	14	Hill's N0 N1 N2	Hill, 1973; Peet, 1974; Southwood, 1978; Piet & Pranovi, 2005	N0 : species richness, N1: the exponential of the Shannon-Weaver diversity index (Shannon and Weaver, 1949, and N2: reciprocal of Simpson's diversity index,	When the problem of variable sample size can be addressed, these metrics have been used to demonstrate long-term temporal and spatial trends in species diversity that have been associated with differences in fishing activity	
	15	Pielou's Evenness Index	Piet & Pranovi, 2005	Pielou's index, J, provides a measure of the evenness of the distribution of the individuals in a sample across the species sampled, calculated by $J = H / \ln(S)$, where H is the Shannon-Weaver index of diversity and S is the number of species in the sample.		
	16	The Connectance Index (CI)	Piet & Pranovi, 2005	it is representative of the complexity of the trophic web and a measure of the development of the ecosystem since one expects that trophic structure changes from linear chain (low CI) to web-like trophic interactions (high CI) in developing ecosystems.	The CI is estimated directly on the basis of diet studies or through models of the trophic chain, need for catch fish	

Table II-1. Continuity

Method	N°	metric	References	Advantages	Difficulties	Observations
number of individuals	17	System Omnivory Index (SOI)	Piet & Pranovi, 2005	Varies in an interval between 0 and 1: a value close to 0 indicates that consumers of the system are specialized, while values close to 1 indicate that consumers feed on many trophic levels Following theoretical analyses and considerations disturbances should reduce connections and therefore should be aspected a reduction of SOI in	However this has not proven already and also theoretical and modelling applications on that are resulting as being controversial	
	18	The Predatory Cycling Index (PCI);	Piet & Pranovi, 2005	PCI is calculated similarly to FCI but excluding the cycling through detritus that generally is the dominant part		
	19	Taxonomic Diversity Indices	Piet & Pranovi, 2005; Warwick & Clarke (1995; 1998)	They are closely related to the Shannon-weaver Index, but they also provide additional information with respect to the level of phylo	the trophic web. This last situation is indicative of a mature state since a complex web	
	20	Pelagic/Demersal fish ratio	Piet & Pranovi, 2005; Diaz, 2001	the dynamics over time of fish community composition can provide useful insights on the food source dynamics or habitat state in marine environments.	is required to maintain cycling in the higher part of the trophic pyramid	

Table II-1. Continuity

Method	N°	metric	References	Advantages	Difficulties	Observations
individual size	21	total biomass per species or per trophic level in situ	Russ & Alcala, 1996 ; Guidetti & Bussotti, 2002 ; Sala <i>et al.</i> , 2012 ; sosa-lopez <i>et al.</i> , 2005 ; Rochet <i>et al.</i> , 2005 ; Bellail <i>et al.</i> , 2002 ; Di Franco <i>et al.</i> , 2009 ; Sahyoun <i>et al.</i> , 2013 ; Gascuel <i>et al.</i> , 2007 ; Tessier <i>et al.</i> , 2011 ; Pelletier <i>et al.</i> , 2008 ; Piet <i>et al.</i> , 2008 ; Fenberg <i>et al.</i> , 2012 ; Guidetti & Bussotti, 2000 ; Bellail <i>et al.</i> , 2003 ; Jenning & Dulvy, 2005 ; Gascuel & Hénichart., 2011 ; Mumby <i>et al.</i> 2013	basic and important indicator of characterizing the fish assemblage	it is to be applied only by scientists, heavy sampling, it need a sampling of size at 2 cm precision to get reliable values	biomass is the most important indicator of the health of fish assemblages across gradients of human disturbance
	22	size frequency distribution	Guidetti <i>et al.</i> 2014, Rochet & Trenkel, 2003 ; Pelletier <i>et al.</i> , 2008 ; Piet <i>et al.</i> , 2008 ; Bellail <i>et al.</i> , 2003 ; Gascuel & Hénichart., 2011 ; Nicholson & Jennings, 2004 ; Piet & Pranovi, 2005	précise, non destructive, renseigne sur différentes catégories ce qui donne une vue d'ensemble et par catégorie en même temps	the cost include the sampling and the sacrificed larvae	
	23	Abundance and density per ecological category	Pais <i>et al.</i> , 2007 ; Guidetti, 2002	more precise information allowing accurate data about target groups of fish separately as Serranidae and Sparidae	the method needs a heavy training,	
	24	proportion of <i>Serranus cabrilla</i> and <i>Coris julis</i>	baychelier, 2013 ; Seytre <i>et al.</i> , 2013	relevant indicator for the angling pressure may be applied simultaneously with other methods of visual census, easy species to identify	the method needs a heavy training,	

Table II-1. Continuity

Method	N°	metric	References	Advantages	Difficulties	Observations
individual size	25	FLI: Fish Large Indicator	Fung <i>et al.</i> 2012; Piet & Pranovi, 2005	It is defined as the biomass of fish above a length hreshold (“large” fish) expressed as a proportion of the total fish biomass		
Sampling (taking the fish)	26	abundance and distribution of functional groups	Mouillot <i>et al.</i> , 2008 ; Mouillot <i>et al.</i> , 2006; Mouillot, 2005; Valls, 2009, Villeger, 2005	description of pertinent functions in the ecosystem and possibility of detection of original functional species in the ecosystems	the sacrifice of the species by experimental fishing, otherwise, it is possible to apply ectrophic indicators through standardized morphometrics proposed in Fishbase	
	27	Genetic diversity Indexes	Piet & Pranovi, 2005	fundamental component of biodiversity and is as critical to sustainability of our natural resources as are diversity of species and ecosystems, allow diagnosis of the relative strengths of the four genetic forces and, indirectly, properties of		
	28	Finn Cycling Index	Finn, 1976 <i>In</i> Piet & Pranovi, 2005	Cycling can be estimated from ecosystem models that estimates flows of the trophic web. These tools provide a comparable estimation of cycling through the Finn Cycling Index (FCI) that represents the fraction of total flows of the system that are cycled	from experimental measures of flows in the ecosystem, which is prohibitive because time-consuming and highly expensive.	
	29	The Transfer Efficiency (TE)	Piet & Pranovi, 2005	have higher values of TE compared to unfished or lightly fished systems	the removal of biomass of fished species can also have positive effects, reducing intraspecific competitions and thus increasing productions and TE	

**Supplementary Matrial II.2. metrics and indicators to monitor fishing activities split
on data collection basis, with correspondent references, advantages and limits**

N	Metric/ Indicator	References	method	measures in the field	advantages	difficulties
1	CPUE per species and per trophic level	Piet & Pranovi, 2005; 2008 ; Laloë <i>et al.</i> , 2001 ; Gascuel <i>et al.</i> , 2008 ; Morand & Kodio ; Tessier <i>et al.</i> , 2011 ; Tessier <i>et al.</i> , 2014 ; Piet & Pranovi, 2009 ; Cury <i>et al.</i> , 2005 ; Lae <i>et al.</i> , 2004 ; Pelletier <i>et al.</i> , 2008 ; Gascuel & Hénichart, 2011 ; Probst <i>et al.</i> 2013	experimental fishing	weight	direct effects of fishing, CPUE provide interesting metrics if their calculation yields accurate abundance indices	which requires good appraisal of fishing effort location and magnitude. Destructive method
2	Fish discards	Piet & Pranovi, 2005; Alverson <i>et al.</i> , 1994 ; Pauly & Christensen, 1995 ; Zeller & Pauly, 2005	experimental fishing		to improve the link between fishing activities and the changes in ecosystem structure and functioning	considerable sampling effort, bycatch in artisanal fishing is discarded just after fishing operation
3	functional diversity	Mouillot <i>et al.</i> , 2008 ; Mouillot <i>et al.</i> , 2006 ; Mouillot, 2005 ; Valls, 2009, Villeger, 2005	experimental fishing	species number	description of pertinent functions in the ecosystem and possibility of detection of functionally original species in the ecosystems	fish are taken to calculate functional traits
4	Elasmobranch/teleost ratio	Piet & Pranovi, 2005	fisheries landings		standardizes the biomass of high trophic level species to lower level preys.	The elasmobranch/teleost ratio is intended to summarize the resulting changes in the fish community between groups that are (generally) characterized by contrasting life-histories (and vulnerability).
5	presence of vulnerable species	Piet & Pranovi, 2005	fisheries landings			

Table II.2. Continuity

N	Metric/ Indicator	References	method	measures in the field	advantages	difficulties
6	Abundance Biomass Comparison Index ABC index	Coeck <i>et al.</i> 1993, Penczak & Kruk 1999 In Aguilar Ibarra, 2004; Agard <i>et al.</i> , 1993; Warwick & Clarke, 1994; Piet & Pranovi, 2005; Clarke & Warwick, 2001	fisheries landings	both species number and weight	abundance and biomass very possible	
7	Shannon index based on weight	lae <i>et al.</i> 2004	artisanal trammel net fishing		easy to calculate $I_{sh} = -\sum (pi/P) \log_2 (pi/P)$, pi: weight per species (kg) in the total catches, P: total catches (kg).	
8	Fishing-in-Balance (FIB) index	Pauly <i>et al.</i> 2000; Gisalsen, 2001; Christensen, 2000 ; Cury <i>et al.</i> , 2005; Volstad <i>et al.</i> , 2003; Piet & Pranovi, 2005	fishing landing		Constant values of FIB index over time identify periods during which the fishing pressure and the carrying capacity of the ecosystem have been stable, or that fishing effort has changed accordingly to the changes in the carrying capacity	mathematical formula implicating energy transfer between trophic level which is difficult to estimate
9	Intrinsic population growth rate, r	Rochet & Trenkel, 2003 ;adams & Greely, 2000	fishing landing		species by species abundance or biomass changes in time (years). It can be estimated as the slope of log (abundances) against time. If it is significantly lower (respectively higher) than 0, the population is decreasing (increasing).	Taking $r = 0$ as the target reference point assumes that without any noticeable impact of fishing, the population would be stable although varying between years.
10	exploitation rate (F/Z)	Rochet & Trenkel, 2003; Piet & Pranovi, 2005	fishing landing		Fishing mortality F is estimated from catch data (landings and discards) and estimated population abundance.	Destructive method

Table II.2. Continuity

N	Metric/ Indicator	References	method	measures in the field	advantages	difficulties
11	total mortality Z	Rochet & Trenkel, 2003; Piet & Pranovi, 2005	fishing landing	both species number and weight	The estimation method for total mortality is based on a simple population dynamics model for a given cohort.	this method is most valid when the intrinsic population growth rate is zero. If the assumptions are appropriate, similar Z estimates should be obtained for different years and r should not be significantly different from zero.
12	proportion of non commercial species in the assemblage	Rochet & Trenkel, 2003	experimental fishing		The proportion of noncommercial species in the community should increase as a result of exploitation. Hence a simple test for change in species composition attributable to fishing is to compare the proportion of noncommercial species over time.	Reference points are difficult to estimate, and those would have to be defined empirically based on historical data.
13	Spear-fishing Index Stdn	Rocklin D., 2010	fishing landings		easy application and calculation, calculate the proportions of species very targeted spearfishing proportions of species hunted opportunistically or never hunted.	
14	Maximum sustainable yield (MSY)	FAO, 1999; Probst <i>et al.</i> 2013	Fisheries landing		corresponds to the maximum theoretic fishable quantity without putting the stocks in danger	Developed for single species and does not take into account species interactions and temporal variations of population
15	Index of declining or increasing species	Piet & Pranovi, 2005	UVC or fisheries landings		These measures are at best coarse and may provide little information about causes of the changes, but are readily interpreted and understood by non-specialists.	

Table II.2. Continuity

N	Metric/ Indicator	References	method	measures in the field	advantages	difficulties
16	Mean k and/or L_{∞} of von Bertalanffy growth curve	Jennings <i>et al.</i> , 1999; Piet & Pranovi, 2005	fishing landings	both species number and weight	k and L_{∞} are parameters of the von Bertalanffy growth curve, which has been established for many species under both experimental and natural conditions. Analysis of the data suggested a long-term decline in the average L_{∞} and increase in the average growth rate (k) of fish in the community.	relies on increasing and extensive historical and current data, costs may be greater than benefits/ income derived from fisheries
17	size spectra or body size	Piet <i>et al.</i> , 2008; Ault <i>et al.</i> , 2005; Lae <i>et al.</i> , 2004; Gascuel & Hénichart, 2011; Piet & Jennings, 2005; Probst <i>et al.</i> 2013; Guidetti & Bussotti, 2000; Piet <i>et al.</i> , 2013; Mouillot <i>et al.</i> , 2006; Tessier <i>et al.</i> , 2011; Nicholson & Jennings, 2006; Rochet <i>et al.</i> , 2005; Ault <i>et al.</i> , 2005; Rochet <i>et al.</i> , 2005; Nicholson & Jennings, 2004; Russ & Alcala, 2000; Graham <i>et al.</i> , 2005; Bellail <i>et al.</i> , 2002; Piet <i>et al.</i> , 2010; Rochet & Trenkel, 2003; Pelletier <i>et al.</i> , 2008; Fenberg <i>et al.</i> , 2012; Guidetti & Bussotti, 2000; Jennings & Dulvy, 2005; Gascuel & Hénichart, 2011; Rochet <i>et al.</i> , 2005; Piet & Pranovi, 2005	experimental fishing	size	give a precise idea of the demographic structure fished and the maximum sizes existing so the real impact of fishing	

Table II.2. Continuity

N	Metric/ Indicator	References	method	measures in the field	advantages	difficulties
18	Slope and intercept of biomass-size spectra	Bellail et al., 2003; Gislason, 2001; Sheldon et al., 1972; Piet and Pranovi, 2005	fishing landing	size	precise	
19	Mean trophic level of captures	Laurans et al., 2005 ; Gascuel et al., 2005 ; Livingston et al., 2006 ; Nicholson & Jennings, 2008 ; Seytre et al. , 2013; Livingston et al. , 2005; Nicholson & jennings, 2004 ; Piet & Jennings, 2005	fishing landings		data for each species trophic level is available for most of the species	if from captures, the destructive method
20	Intrinsic vulnerability Index	Cheung et al. 2007, Lloret & Font, 2013	fishing landing	number	the use of intrinsic vulnerability of each species, stipulating that most vulnerable species are the one with high longevity, large size at first maturity,	
21	Mean age of the population	Piet & Pranovi, 2005	Fishing landing	sampling (taking the fish)	reliable index about the demographic structure of the assemblage	needs to sacrifice the species to estimate the age from otoliths.
22	Number of infractions with a real pursuit	Pelletier et al. , 2008 ; Gascuel & Hénichart., 2011; Marques et al. 2013; Tessier et al. 2011	frequentation surveys	Frequentation	indirect indicator	it is not so informative because a limited number of infractions does not mean the absence of infractions... and we can not conclude about the effects on fish assemblage

*Chapter III: Fish assemblages
along the coasts of Tunisia: a
baseline study to assess the
effectiveness of future Marine
Protected Areas*

The literature review showed metrics and indicators that were used to assess fish assemblage in response to conservation measures and to coastal fishing pressure. MPAs are known to be particularly effective for protecting fish assemblages (Guidetti *et al.*, 2014, Mellin *et al.*, 2016). Many fish species, in fact, are targeted by fisheries, and within MPAs their populations experience a reduction of fishing mortality. In the Mediterranean Sea, recent studies provided evidence that well managed and enforced MPAs can determine clear ecological responses (particularly on large fish predatory species; Guidetti *et al.*, 2014) and fishery benefits (Di Franco *et al.*, 2016). Accomplishing accurate, rapid and cost-effective surveys is an important conservation and management tool in Marine Protected Areas (Murphy & Jenkins, 2010).



**Accepted paper: Fish assemblages along the coasts of Tunisia: a baseline study
to assess the effectiveness of future Marine Protected Areas, in press
Mediterranean Marine Science**

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III.1. Abstract

The present study investigated coastal fish assemblages, using Underwater Visual Census (UVC) transects, that can be used as a baseline, at 3 locations in Tunisia (south Mediterranean basin), where 3 MPAs will be established, before the implementation of protection measures. At each location, we used a sampling design where fish censuses were performed in two types of zone: zones that will be inside MPAs, and zones that will remain outside. On the whole, 49 taxa belonging to 19 families were censused. Our findings provided evidence of overexploitation throughout the sampled areas, especially in terms of dominance of small- and medium-sized individuals of commercially relevant species. Our analyses, moreover, did not show any significant difference between fish assemblages (considering both density and biomass of whole assemblages, the different trophic categories, and size distribution of commercial species) between future-protected and unprotected zones. Overall, results suggest that: 1) current fish assemblages at the three studied locations are likely to be seriously impacted by fishing activities, and 2) these data could be used as reliable baselines to assess the effectiveness of protection measures within the MPAs that will be established in the future. Our study is the first in Tunisia, and in North African coasts, that assessed distribution patterns of coastal fish assemblages by means of UVC, using a formal spatially replicated sampling design for resource management.

Key words: underwater visual census (UVC); Marine Protected Areas; South Mediterranean; Tunisia

III.2. Introduction

Tunisia is located in the south-central Mediterranean Sea. It includes about 1670 km of coastline. It is considered as a crossroad between the eastern and western Mediterranean as it lies biogeographically in the Strait of Sicily, known for its high biodiversity, especially in terms of fish diversity (Bianchi *et al.*, 2012). As in the rest of the Mediterranean (Sala *et al.*, 2012 and references therein), professional (artisanal and industrial) and recreational fishing, along with a number of illegal practices, are seriously threatening coastal fish assemblages in Tunisia (Coll *et al.*, 2010; CAR/ASP & PNUE-PAM, 2014; Halouani *et al.*, 2015). In this context, Marine Protected Areas

(MPAs) that include fully protected zones (also referred to as no-take zones or marine reserves) are important tools for conservation and management (PISCO & UNS, 2016). Worldwide, MPAs with fully protected zones have been clearly demonstrated to be effective for protecting fish assemblages (Di Franco *et al.*, 2009; Guidetti *et al.*, 2014, Mellin *et al.*, 2016; PISCO & UNS, 2016; Bergseth *et al.*, 2017). In the Mediterranean Sea, recent studies provided significant evidence that well-managed and well-enforced MPAs trigger clear ecological responses (particularly from large predatory fishes; Guidetti *et al.*, 2014; Giakoumi *et al.*, 2017) and provide fishery benefits (Di Franco *et al.*, 2016).

In most MPAs worldwide, scientists monitor the effectiveness of MPAs by assessing fish assemblages using Underwater Visual Census (UVC) methods after the establishment of the MPA, often comparing data collected under protected and fished conditions (e.g. Sala *et al.*, 2012; Edgar *et al.*, 2014; Aburto-Oropeza *et al.*, 2015; Caldwell *et al.*, 2016). Some authors have highlighted the importance of having time reference data, to be able to compare patterns before and after MPA implementation. This can be done by formally adopting the so-called “Before vs After Control Impact” experimental designs in the specific context of MPA studies (e.g. Guidetti, 2002; Pelletier *et al.*, 2008). The point is that comparing fish assemblage patterns only after MPA implementation by sampling at protected and fished control sites, might affect the inference regarding the ‘reserve effect’ (i.e. the response to protection, especially in terms of increased abundance, size and biomass of fish as a consequence of protection measures) because, without 'before' data, uncontrolled factors, e.g. habitat and seascape complexity (García-Charton *et al.*, 2000; Guidetti, 2002; Huntington *et al.*, 2010), can mask the effects of protection.

In this perspective, the present study has been undertaken to assess the status of coastal fish assemblages at three locations in Tunisia that will host MPAs in the near future (CAR/ASP & PNUE-PAM, 2015, but see also: http://www.apal.nat.tn/site_web/contenu/creation_et_gestion_des_amcp.html). The aim is to describe the status of these fish assemblages and use these data as ‘before data’ to test the effectiveness of MPAs once they are established and protection measures are implemented. To the best of our knowledge, this is the first study carried out in Tunisia, and along the coasts of North Africa, that has assessed distribution patterns of coastal fish assemblages by means of UVC, that used a formal spatially replicated sampling design.

III.3. Methods

III.3.1. Sampling locations

UVC sampling was performed at three locations, referred to as Tabarka, Cap Negro-Cap Serrat and Kuriat Islands. Each location encompassed 4 sites that will be protected (i.e. that will be included within an MPA), and 2 adjacent sites (controls) that will remain open to fishing. Tabarka is situated on the west coast of Tunisia and the MPA will cover 327.855 ha, down to 40-m depth; Cap Negro-Cap Serrat is located in the north, and the MPA will cover 1 300 ha, down to 45-m depth; Kuriat islands, situated off the east coast, will host an MPA covering 19 674 ha, down to 40-m depth (Figure III.1).

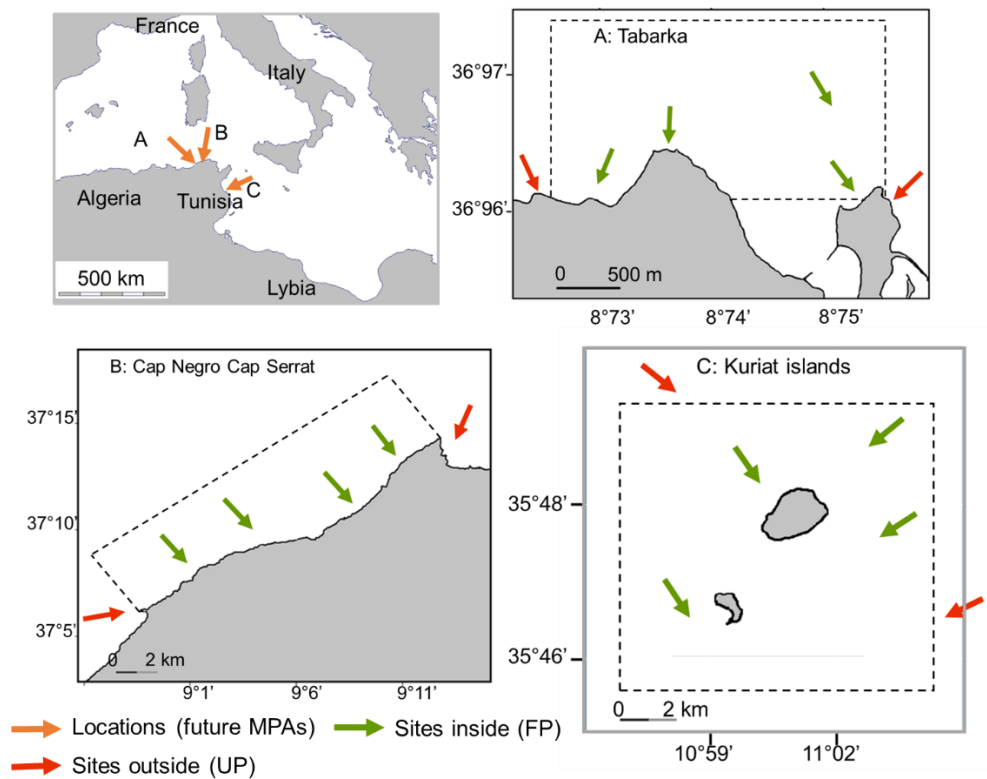


Figure III.1. Locations where MPAs will be established along the Tunisian coast. Location of future protected sites (FP) and the ones outside (that will remain unprotected) (UP) (separated with dotted lines indicating borders of future MPAs as they are proposed in management plans)

III.3.2. Sampling design and data collection

Six sampling sites were surveyed at each location (4 sites that will in the future be protected and 2 that will remain unprotected), using the visual census transect method (see Harmelin-Vivien *et al.*, 1985) performed on rocky reefs from 10 to 20 meters depth. All sampling sites have similar characteristics in terms of habitat type, with rocky bottoms covering ~70%, and *Posidonia* meadows and sand covering the remaining ~30% of the substrate. One sampling survey per year was conducted (from 2014 to 2016 at Tabarka and Kuriat Islands, and in 2014 and 2016 at Cap Negro-Cap Serrat) during the warm season (from August to September) and under similar weather and sea conditions. The same person performed all fish counts at all sites, diving in one direction at constant speed, and performing three types of transects in terms of length and width: (1) transect A: 25 m x 5 m for necto-benthic fish (e.g. sea bream), (2) transect B: 35 m x 10 m for large mobile high-level predators (e.g. grouper), and (3) transect C: 10 m x 1 m for crypto-benthic fish (e.g. Gobidae) (Prato *et al.*, 2017 for further methodological details) (see Supplementary material III.1 for the species list). Three replicates of each transect type were performed at each site and sampling year for a total of 144 replicates conducted in this study. At each transect, each species encountered was identified and its abundance recorded. Fish size (total length) was recorded within 5 cm size classes for large sized fish (species maximum size > 50 cm), 2 cm size classes for other necto-benthic fish species and 1 cm for small crypto-benthic fish (following Prato *et al.*, 2017). Based on density and size data, fish biomass was estimated using length-weight relationships (Froese & Pauly, 2017).

III.3.3. Data analyses

Total fish density and biomass (pooling all species censused and calculated for all transect types together) were expressed as number of individuals or grams per square meter. Species richness was expressed as number of fish taxa per transect. Fish species were also characterized and pooled, in terms of density and biomass, according with their trophic category (see Bell & Harmelin-Vivien, 1983; Sala, 2004; and Guidetti & Sala, 2007): large predators, small piscivores, invertivores 1 (major predators of sea urchins), invertivores 2 (with diet seldom including sea urchins), planktivores and herbivores (see Supplementary material III.1 for further details). Then, for commercially relevant species (see table in Supplementary material III.2), each recorded fish

was assigned to one of three size classes, i.e. small, medium and large, corresponding to the lower, intermediate and upper 33% range of sizes reported in the literature (Froese & Pauly, 2017) and size-class frequencies were calculated for each location (see Supplementary material III.2 for the total number of individuals per species used to build frequency distributions).

Overall fish assemblage structure (based on density and biomass data) was analysed using multivariate statistical techniques. Specifically, two “taxon x samples” matrices of species density and biomass ($n = 49$ taxa, $n = 144$ samples) were analysed. Univariate techniques were used for: (1) species richness (one matrix $n = 1$ variable, $n = 144$ samples), (2) total density and total biomass (two other matrices: $n = 1$ variable, $n = 144$ samples), and, (3) density and biomass per trophic category (12 matrices: $n = 1$ variable, $n = 144$ samples). Univariate and multivariate analyses were performed using a four-way permutational analysis of variance (PERMANOVA, Anderson, 2001). For all Permanovas, the following factors have been taken into account: factor “Protection” (P) (2 levels, Future Protected (FP) and Unprotected (UP)) was considered as fixed; factor “Location (Lo)” (3 levels: Kuriat, Cap Negro-Cap Serrat, Tabarka) and factor “Site” (Si), (2 to 4 levels) nested in each level of P and, factor “Time (Ti)” (2 to 3 levels), were both considered as random. We used MonteCarlo permutations whenever the number of possible permutations was < 200 . The PRIMER 7 package implemented with PERMANOVA+ was used to perform the analyses.

III.4. Results

III.4. 1. *Multivariate analyses*

Overall, fish assemblages comprised 49 taxa belonging to 19 families: 48 taxa were found in Tabarka, 45 at Kuriat islands and 34 at Cap Negro-Cap Serrat. Sparidae and Labridae were strongly represented families in terms of number of species (see Table in Supplementary material III.1).

Multivariate analyses performed on density data show that fish assemblage structure changed significantly between sites that will be protected and the ones that will remain outside MPAs (factor ‘P’ significant; Table III.1). Assemblage structures in terms of both density and biomass, also, changed significantly over time, but with changes that were not the same at the spatial scales of locations and sites (interaction ‘TixLoxSi(P)’ significant; Table III.1).

Table III.1. PERMANOVA (multivariate analysis) on square root transformed data of fish density and biomass. Ti: Time; Lo: Location; Si: Site; P: Protection. *p < 0.05; **p < 0.01; ***p < 0.001.

Source	df	Density		Biomass	
		MS	Pseudo-F	MS	Pseudo-F
Ti	2	10405	5.00***	13488	5.43***
Lo	2	7504.7	1.25	11354	1.65*
P	1	12003	2.16*	8628.8	1.43
Si(P)	5	4527.8	2.09	4391	1.71*
TixLo	3	4141	2.01*	4415.5	1.97**
TixP	2	2731.4	1.31	4065.9	1.63
LoxP	2	3862.1	1.04	5873.8	1.25
TixSi(P)	10	2239.4	2.02***	2621.2	1.58***
LoxSi(P)	6	3380.2	1.61*	3701.1	1.64*
TixLoxP	3	2316.2	1.12	2733.8	1.22
TixLoxSi(P)	8	2101.4	1.89***	2260.2	1.36*
Res	99	1106.6		1657.3	
Total	143				

III.4. 2. Univariate analyses

Mean species richness ranged from 8.2 ± 0.7 taxa in UP Kuriat to 14.2 ± 1.4 taxa in UP Tabarka (Figure III.2-a). Mean fish density (pooling all species) ranged from 0.7 ± 0.1 ind/m² in UP Kuriat to 1.5 ± 0.3 ind/m² in UP Cap Negro Cap Serrat (Figure III.2-b). Mean fish biomass (again pooling all species) ranged from 11.9 ± 2.9 in UP Kuriat to 50.1 ± 7.9 gr/m² in UP Tabarka (Figure III.2-c).

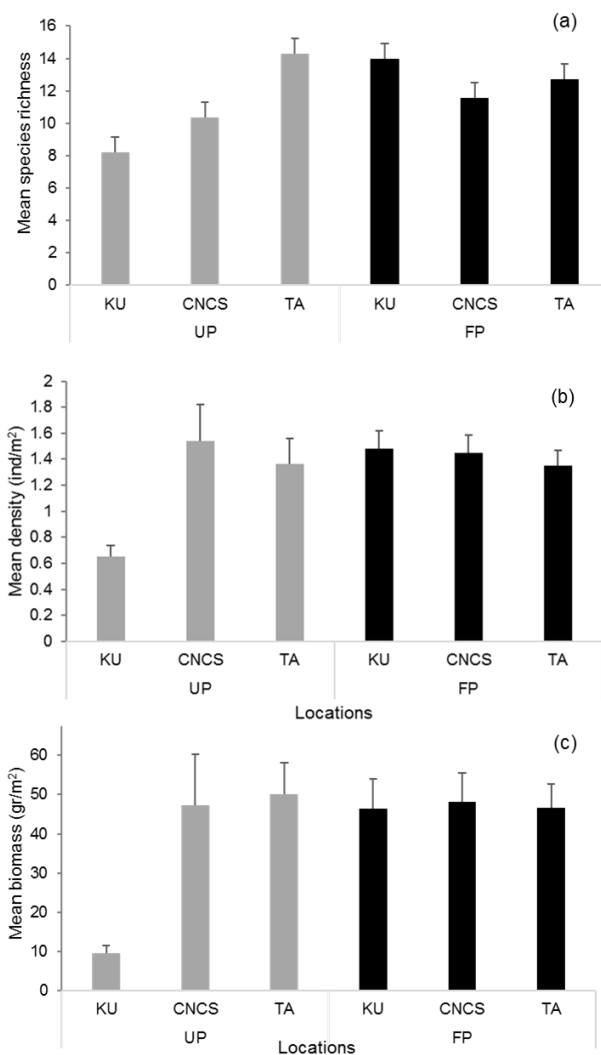


Figure III.2. Mean species richness (a), mean density (b) and mean biomass (c) (\pm standard error) per location (KU: Kuriat islands, CNCS: Cap Negro-Cap Serrat, TA: Tabarka) and protection level (UP: Unprotected, FP: Future Protected).

Univariate analyses showed that: 1) none of the three variables (species richness, total density and biomass of fish) significantly differed between UP and FP (the factor 'P' was never significant; Table III.2), 2) species richness was significantly variable over sampling times, factor 'Ti' significant); 3) fish density displayed a variability over sampling times that differed at both the spatial scales of locations and sites, interaction 'TixLoxSi(P)' significant); 4) fish biomass changed over time (factor 'Ti' significant) and was significantly variable at the scale of locations (factor 'Lo' significant)).

Table III.2. PERMANOVA (univariate analysis) on species richness, total density and total biomass of fish. Ti: Time; Lo: Location; Si: Site; P: Protection. *p < 0.05; **p < 0.01; ***p < 0.001.

Source	df	Species richness		Density		Biomass	
		MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
Ti	2	394.25	21.59***	9546.8	13.46***	11532	10.326***
Lo	2	221.54	4.43	1415.7	0.74	8621.9	3.9498**
P	1	287.76	1.95	6112.3	2.77	5629.4	1.9601
Si(P)	5	178.62	1.41	1428.5	1.94	948.87	0.83053
TixLo	3	150.75	0.51	1532.4	1.63	1443.7	1.4839
TixP	2	86.99	0.79	1316.2	1.85	2748.6	2.4612
LoxP	2	123.76	2.94	931.1	1.03	5348.9	2.1407
TixSi(P)	10	86.24	2.09	761.65	1.932*	1166.8	1.4275
LoxSi(P)	6	153.41	1.01	1632.2	1.71	936.74	0.95839
TixLoxP	3	108.46	1.79	231.28	0.24	1951.3	2.0056
TixLoxSi(P)	8	85.40	1.85	959.02	2.43**	979.65	1.1985
Res	99	49.72		394.22		817.41	
Total	143						

III.4.3. Trophic category density and biomass

Density per trophic category displayed different patterns (Figure III.3, Table III.3). Density patterns of herbivore fish did not change for any factor considered here. Large predator and invertivores 1 densities showed a significant temporal variability ('Ti' significant). Small predator density was not coherent over time between locations (interaction 'TiXLo' significant). Finally, mean densities of invertivores 2 fish changed over time at both the spatial scales of locations and sites (interaction 'TiXLoXSi(P)' significant), while density of planktivores changed over time at the scale of locations (interaction 'TiXLo' significant).

Patterns of biomass also changed, depending on the trophic category (Figure III.4, Table III.4). Biomass patterns of herbivores and invertivores 1 did not change for any factor considered here. Biomass of large predator fish showed a significant variability over time ('Ti' significant). Small predator biomass was not consistent between times and locations (interaction 'TiXLo' significant). Mean biomass of herbivores was not coherent either, in the spatial (locations and sites) and temporal scales (interaction 'TiXLoXSi(P)' significant). Finally, biomass of invertivore 2 changed over time, but differently for sites that will be protected compared to sites that will remain outside MPAs (interaction 'TiXP' significant).

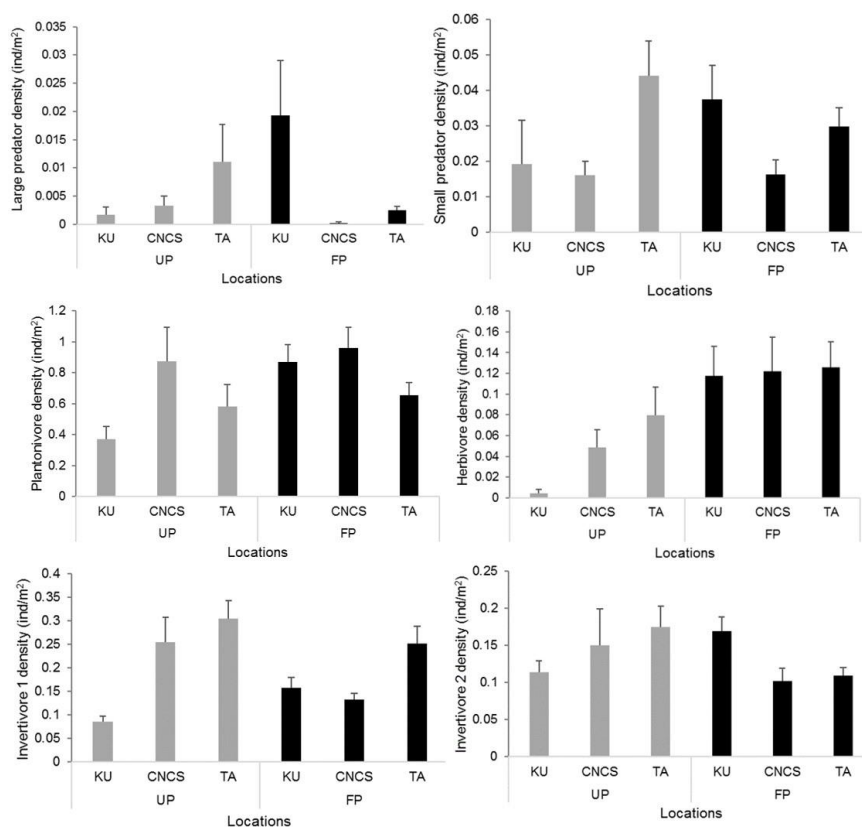


Figure III.3: Mean density (\pm standard error) per trophic category at the sampling locations (KU: Kuriat Islands, CNCS: Cap Negro-Cap Serrat, TA: Tabarka) and per protection level (UP: Unprotected, FP: Future Protected).

Table III.3. PERMANOVA (univariate analysis) on density data per trophic category. Ti: Time; Lo: Location; Si: Site; P: protection. *p < 0.05; **p < 0.01; ***p < 0.001.

Density		Large predator		Small predator		Planktivore		Herbivore		Invertivore 1		Invertivore 2	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
Ti	2	9958	0.00*	0.01	6.55*	1.70	5.76*	9954	0.02	0.17	6.15*	0.09	10.81**
Lo	2	0.00	0.92	7,8785E-06	0.09	1.04	0.68	0.03	0.64	0.13	3.07	0.00	1.16
P	1	5,6519E-08	0.63	0.00	0.67	1.63	2.32	0.10	3.98	0.06	3.97	0.00	1.05
Si(P)	5	0.00	1.36	0.00	0.88	0.44	1.48	0.00	0.84	0.02	0.79	0.01	1.47
TixLo	3	0.00	1.01	0.00	8.94**	1.10	8.38**	0.01	1.11	0.01	0.48	0.00	0.19
TixP	2	2,4098E-06	0.00	0.00	0.76	0.45	1.55	0.02	2.88	0.00	0.04	0.00	0.17
LoxP	2	0.00	1.12	0.00	1.19	0.21	0.59	0.00	0.34	0.05	1.29	0.01	1.98
TixSi(P)	10	0.00	0.60	0.00	1.65	0.30	1.28	0.00	0.33	0.03	1.64	0.00	1.18
LoxSi(P)	6	0.00	0.94	0.00	0.92	0.56	4.39*	0.05	3.52	0.03	1.53	0.01	0.79
TixLoxP	3	0.00	0.86	0.00	0.83	0.02	0.21	0.00	0.44	0.02	0.88	0.00	0.14
TixLoxSi(P)	8	0.00	0.36	0.00	0.49	0.12	0.53	0.01	0.84	0.02	1.42	0.01	2.41*
Res	99	0.00		0.00		0.23		0.01		0.01		0.00	
Total	143												

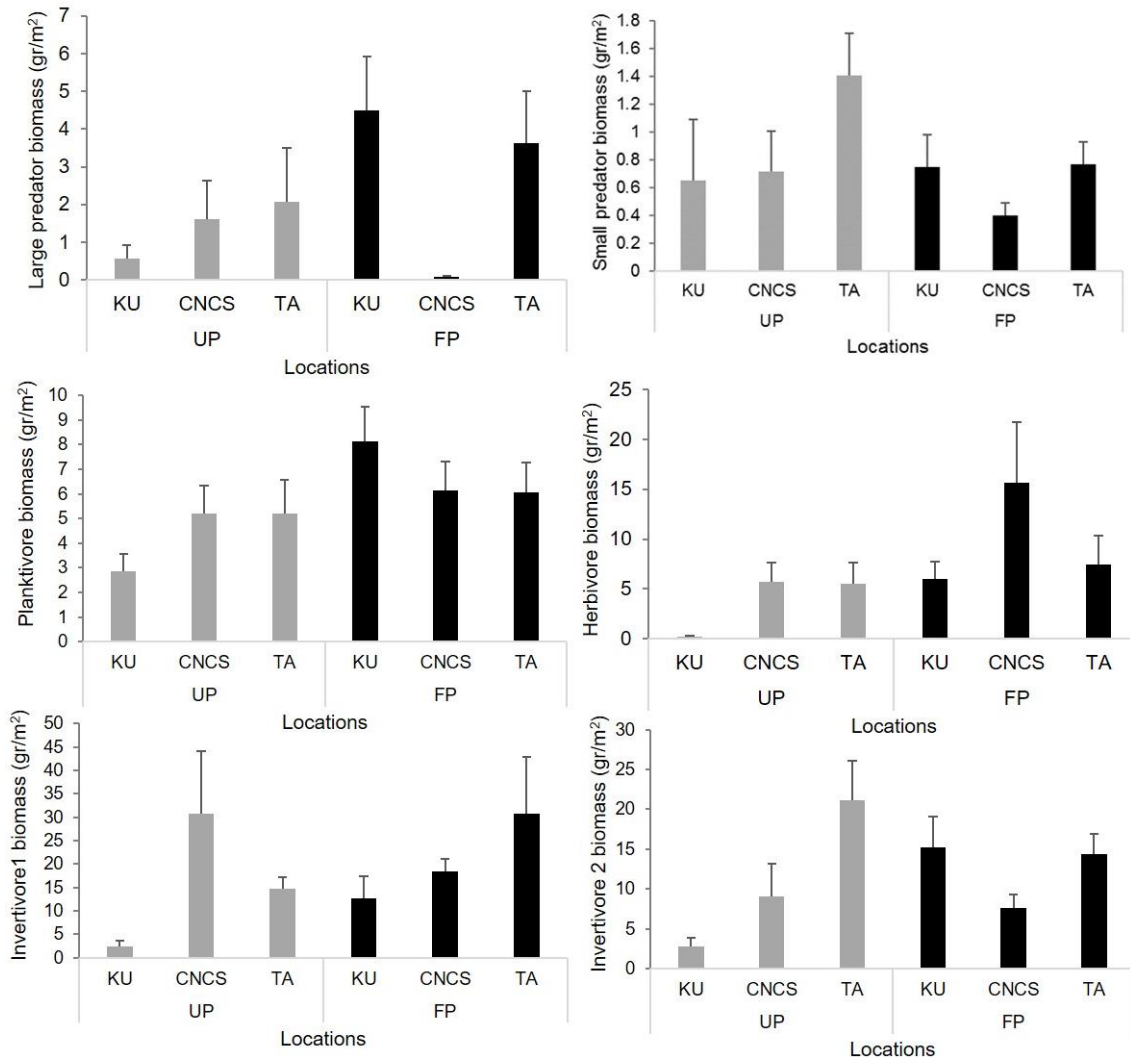


Figure III.4: Mean biomass (\pm standard error) per trophic category at the sampling locations (KU: Kuriat Islands, CNCS: Cap Negro-Cap Serrat, TA: Tabarka) and per protection level (UP: Unprotected, FP: Future Protected)

Table III.4. PERMANOVA (univariate analysis) on biomass data per trophic category. Ti: Time; Lo: Location; Si: Site; P: protection. *p < 0.05; **p < 0.01; ***p < 0.001

Biomass		Large predator		Small predator		Planktivore		Herbivore		Invertivore 1		Invertivore 2	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
Ti	2	620.92	4.20*	4.55	2.38*	135.7	2.21	369.98	2.51	2159.8	1.52	4049.7	53.69***
Lo	2	348.03	1.20	1.21	0.22	3.261	0.62	376.76	0.89	1601.4	0.99	440.13	2.62
P	1	188.36	0.58	2.52	0.73	140.39	3.31	517.01	1.15	457.57	0.81	235.55	0.60
Si(P)	5	367.81	2.55	2.03	1.02	32.69	0.51	177.08	1.24	1182.6	0.84	126.71	1.93
TixLo	3	227.73	1.50	8.40	11.43**	65.21	1.15	34.65	0.06	1201.5	0.68	95.65	0.69
TixP	2	216.16	1.46	4.22	2.20	32.08	0.52	422.76	2.87	932.43	0.65	380.28	5.04*
LoxP	2	424.44	1.32	1.20	0.74	30.04	2.66	75.58	0.48	1997.5	1.12	639.65	1.50
TixSi(P)	10	140.1	0.72	2.04	1.77	65.48	1.78	137	0.66	1372.9	0.82	56.01	0.29
LoxSi(P)	6	180.27	1.20	0.03	0.04	31.73	0.55	990.29	1.93	2194.7	1.24	122.59	0.89
TixLoxP	3	246.18	1.63	2.46	3.34	2.10	0.03	258.09	0.51	1171.7	0.66	378.13	2.73
TixLoxSi(P)	8	149.08	0.77	0.71	0.62	57.36	1.56	516.91	2.49*	1758.5	1.05	135.93	0.71
Res	99	193.59		1.15		36.69		207.3		1662.1		191.44	
Total	143												

III.4.4. Size-class frequency distribution

Overall, small and- medium -sized individuals dominated and large-sized fish were fairly rare (Figure III.5). Large-sized *Epinephelus marginatus*, *Dentex dentex*, *Sparus aurata* and *Serranus cabrilla* were censused only in UP, at Cap Negro-Cap Serrat and Tabarka. Large-sized *Epinephelus costae* and *Coris julis* were only recorded in FP at Tabarka. Large-sized individuals belonging to other species, such as *Sciaena umbra*, *Diplodus sargus*, *Diplodus vulgaris*, *Diplodus annularis*, *Diplodus puntazzo* and *Mullus surmuletus*, were recorded in both UP and FP conditions.

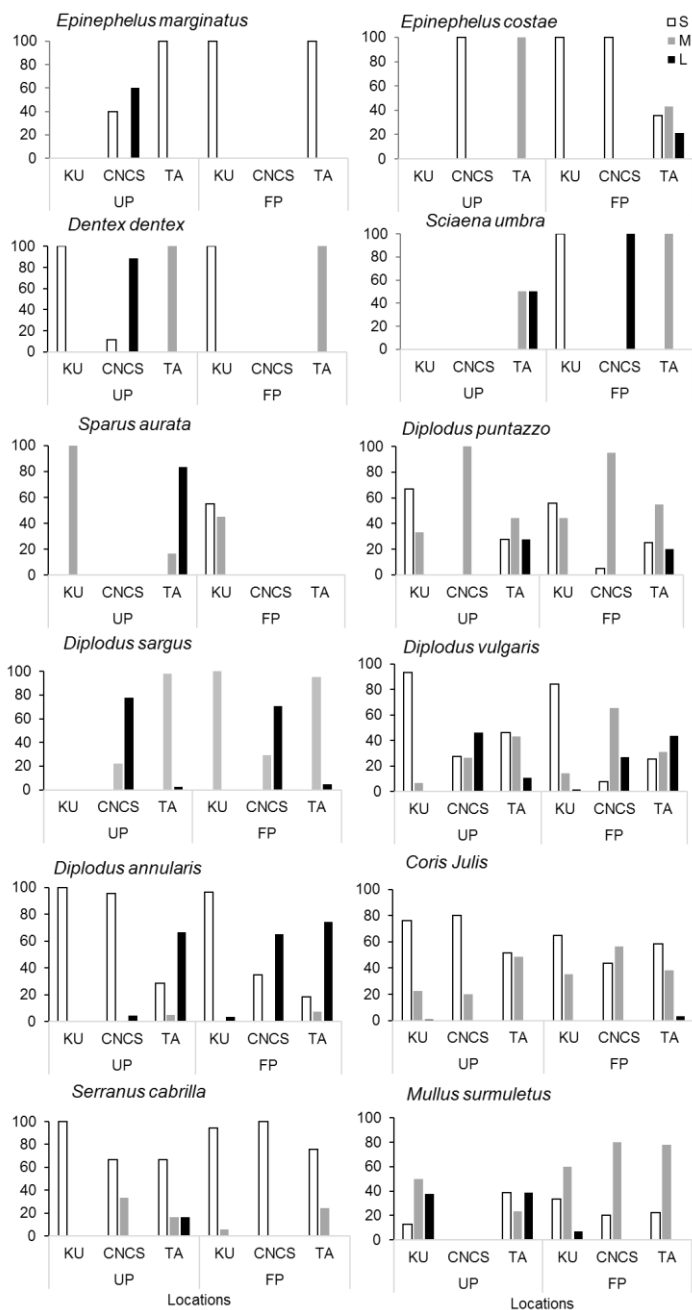


Figure III.5. Size-class (S: small, M: medium and L: large) frequency distribution (%) of relevant target fishes in Unprotected (UP) and Future Protected (FP) zones at the three studied locations (KU: Kuriat Islands, CNCS: Cap Negro-Cap Serrat, TA: Tabarka), (Number of individuals used to calculate percentages is given in Supp. Mat. III.2)

III.5. Discussion

The taxa composition of the assemblages censused at the three locations investigated in Tunisia showed that fish belonging to Sparidae, Labridae and Serranidae families were the most strongly represented in terms of number of species, a classic pattern for the western Mediterranean fish assemblage (e.g. García-Charton & Pérez-Ruzafa, 2001; Seytre & Francour, 2014). Fish belonging to Sparidae and Labridae families were also the most represented at the three studied locations in terms of both density (minimum 59% of total density) and biomass (minimum 71% of total biomass). It is worth noting the presence of vulnerable and endangered species, such as the grouper *Mycteroperca rubra* and *Epinephelus marginatus*, and the common guitarfish *Rhinobatos rhinobatos* (see IUCN red list of threatened species, (IUCN, 2017)).

Fish assemblage structure, both in terms of density and biomass (see multivariate results), was quite variable over time and space. It differed slightly between sites that will be protected and sites that will remain outside MPAs. The observed patterns can be attributed to factors that are for sure independent of protection (not yet in place in the studied locations), such as habitat type distributions, slope, algal cover, bottom rugosity or seascape complexity, that have not been taken into account in the present study (see Garcia-Charton *et al.*, 2000). Thus, this outcome shows that other factors could contribute to differences in fish assemblage density and has, therefore, implications for future monitoring. This result stresses once more the usefulness of adopting proper sampling designs, such as, in this case, the crucial importance of ‘before data’ in the framework of BACI (before-after/control-impact) designs, to properly test hypotheses related to MPA effectiveness (Guidetti, 2002).

Mean values of total fish density assessed in this study are far lower than those assessed in many well-protected MPAs and, on the other hand, comparable with the values reported from unprotected rocky reefs, open to fishing in the Mediterranean (e.g. Harmelin-Vivien *et al.*, 2008; Guidetti *et al.*, 2014; La Mesa *et al.*, 2017). Concerning the total fish biomass, the values observed in the present study range between ~ 11 and 50 gr/m^2 , with an overall average around 40 gr/m^2 . These values are lower than those reported from many well-managed MPAs in the Mediterranean (e.g. Tavolara, Cabo de Palos, Torre Guaceto, Medes Island, Carry-le-Rouet, Banyuls-sur-Mer)

where values range between ~ 65 and 120 gr/m^2 (Harmelin-Vivien *et al.*, 2008, Guidetti *et al.*, 2014). The fish biomass values observed in this study in Tunisia are in any case relatively high, considering other Mediterranean sites open to fishing, where average values range from ~ 5 to 30 gr/m^2 (Guidetti *et al.*, 2014).

With regard to the fish biomass, it is widely accepted that this variable is the most relevant (much more important than density) as a basis for drawing conclusions regarding the effects of protection in MPAs (McClanahan & Mangi, 2000; Harmelin Vivien *et al.*, 2008; Guidetti & Sala, 2007). Biomass, in fact, integrates information regarding abundance and size of fish. This is of paramount importance, considering that fishing usually targets large individuals of commercial species (Sandin *et al.*, 2008). In our data set, it is important to highlight the presence of few large-sized fishes (e.g. *Dasyatis pastinaca* and *Rhinobatos rhinobatos*). However, considering they are quite little abundant, they did not significantly contribute to average values of total fish biomass at our assessment. From this perspective, most of the fish biomass estimated at the different locations in Tunisia is attributable to invertivores ($\sim 53\%$), planktivores ($\sim 10\%$) and herbivores ($\sim 11\%$) fishes, while the contribution of large predators was negligible, i.e. no more than 9% , versus $\sim 38\%$ in Cabo de Palos (Spain), Tavolara (Italy) and Scandola (France) (Prato *et al.*, 2017).

As far as size of fish is concerned, fish size at the studied locations was quite variable (with no evident differences between sites that will be protected and sites that will remain outside MPAs in the future) and that fish assemblages were generally dominated by small- and medium-sized fishes. Previous studies have shown that large individuals of commercial fishes are chiefly removed by fishing as they are the most valuable on the markets (Pauly *et al.*, 1998). The fact that large individuals are missing is thus widely considered a symptom of overexploitation and of community-wide impact of fisheries (Pauly *et al.*, 1998; Guidetti & Sala, 2007).

Results of the present study regarding the evidence commented on above suggest that fish assemblages at the studied Tunisian locations are likely to be impacted by fishing, which is capable of removing a remarkable fraction of the fish biomass, in particular that of large-sized predatory fishes such as *Epinephelus marginatus*, *Epinephelus costae* and *Dentex dentex*. Meanwhile, creating MPAs in these

locations is ongoing, to protect biodiversity and enhance sustainable economic activities (CAR/ASP & PNUE-PAM, 2015). Like other well enforced Mediterranean MPAs (Guidetti *et al.*, 2014), we can expect that Tunisian future MPAs, if well enforced, could provide benefits to fish assemblage, and in the long-term to fisheries.

The present study is the first carried out in Tunisia (and, to the best of our knowledge, also the first performed along the southern coasts of the Mediterranean Sea) that has reported quantitative data and assessed distribution patterns of coastal fish assemblages using the appropriate underwater fish visual census (UVC; Harmelin-Vivien *et al.*, 1985; Prato *et al.*, 2017), and adopting a formal spatio-temporally replicated sampling design (Guidetti, 2002; Pelletier *et al.*, 2008; Bonaldo *et al.*, 2017).

From a methodological viewpoint, the UVC transect technique, is widely accepted as a method that gathers quantitative data in the framework of formal and appropriate sampling designs, and offers a suitable basis for drawing reliable conclusions regarding the effects of protection within MPAs (Guidetti, 2002; Caldwell *et al.*, 2016). This study satisfies both criteria, and could set an important precedent for other studies that, hopefully, will be carried out in Tunisia and in other countries in the southern and eastern sectors of the Mediterranean in the future. This is important considering that a number of surveys and meta-analyses have reported that many studies have been done on the effects of Mediterranean MPAs, but almost all of them concern MPAs in Spain, France and Italy, fewer in Greece and Turkey, while the rest of the Mediterranean (more than half of its coasts) is virtually uncovered (Giakoumi *et al.*, 2017 and references therein).

In conclusion, this study can be considered as an important baseline for assessing in the future the health status of fish assemblages along the coasts of Tunisia, and the effects of protection measures that will be introduced after the implementation of the three planned MPAs. In addition, this study could trigger other investigations in other North African Mediterranean countries and in the eastern Mediterranean that will allow to get a more exhaustive assessment of the effects of MPAs in the region. In Tunisia and in other south-eastern Mediterranean countries, it is crucial, aside of performing monitoring fish assemblages, to enable fish assemblages to recover, that the proposed

zoning of MPAs is applied and restrictions, especially in no-take zones, enforced. Otherwise, the expected benefits for fish, overall biodiversity and ecosystems, along with a number of positive effects for society (e.g. with regard to sustainable economic activities such as artisanal fishing and diving) will not be forthcoming (PISCO & UNS, 2016). In this framework, monitoring, using appropriate methods for collecting data within proper sampling design, is an extremely important governance tool.

Financial support

This paper is part of the PhD. thesis of Emna Ben Lamine. This work has received funding from the MedMPAnet Project and MedKeyHabitat project (both coordinated by the SPA/RAC), the “Agence de Protection et d’Aménagement du Littoral” (APAL), the local NGO “Abysses Plongée” (Tunisia), the Agence de l’Eau Rhône-Méditerranée-Corse (France) and the MMMPA (Training Network for Monitoring Mediterranean Marine Protected Areas project).

Acknowledgments

The authors gratefully acknowledge the help of scuba diving instructors Mourad Saidane, Sofiane Ben Aissa, Mahdi Aguir, Wissem Houiji and Abderrahmane Mliki. The diving equipment was partially provided by the company Aqualung.

Supplementary material

Supplementary material III.1,

Table III.5. Mean densities (individual/m²), per location (KU, Kuriat, CNCS Cap Negro Cap Serrat, TA: Tabarka), with trophic category (Troph), (se: standard error) and Tunisian commercial interest description for each species (PLA: Planktivore, SCCB: Small Carnivore Cryptobenthic, LP: Large Predator, INV1: invertivore 1, INV2: Invertivore 2, SP: Small Predator, HERB: Herbivore, Nc: No commercial interest, Lc: Low commercial interest, Hc: High commercial interest, T: transect type (A: 25x5m, B:35x10m; C: 10x1m)

Family	Species	KU	se	CNCS	se	TA	se	Troph	Commercial interest	T
Apogonidae	<i>Apogon imberbis</i>	0.0106	0.0111	0.0028	0.0003	0.0078	0.0028	PLA	Nc	A
Atherinidae	<i>Atherina boyeri</i>	0.0244	0.0423	1.5277	0.1964	0.2860	0.4954	PLA	Lc	A
Blennidae	<i>Parablennius rouxi</i>	0.0037	0.0064	0	0	0.0240	0.0416	SCCB	Nc	C
	<i>Parablennius pilicornis</i>	0.1129	0.1956	0.0055	0.0078	0.0962	0.1667	SCCB	Nc	C
Carangidae	<i>Lichia amia</i>	0	0	0	0	0.0010	0.0017	LP	Hc	B
	<i>Seriola dumerili</i>	0	0	0	0	0.0002	0.0005	LP	Hc	B
Dasyatidae	<i>Dasyatis pastinaca</i>	0.0045	0.0079	0	0	0.0007	0.0012	LP	Hc	B
Gobidae	<i>Gobius spp.</i>	0.0055	0.0096	0.0194	0.0274	0.0092	0.0160	SCCB	Nc	C
	<i>Gobius niger</i>	0.0001	0.0002	0	0	0	0	SCCB	Nc	C
Labridae	<i>Coris julis</i>	0.4082	0.3601	0.3401	0.4483	0.6240	0.5948	INV1	Lc	A
	<i>Labrus merula</i>	0.0017	0.0019	0.0055	0.0003	0.0031	0.0023	INV2	Lc	A
	<i>Labrus viridis</i>	0.0302	0.0494	0.0008	0.0006	0.006	0.0064	INV2	Lc	A
	<i>Symphodus cinereus</i>	0	0	0	0	0.0075	0.0127	INV2	Lc	A
	<i>Symphodus doderleini</i>	0.0202	0.0256	0	0	0.0074	0.0128	INV2	Lc	A

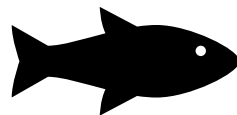
	<i>Symphodus mediterraneus</i>	0.0379	0.0543	0.0017	0.0018	0.0143	0.0095	INV2	Lc	A
	<i>Symphodus melops</i>	0	0	0	0	0.0007	0.0009	INV2	Lc	A
	<i>Symphodus ocellatus</i>	0.0137	0.0093	0.0015	0.0003	0.0231	0.0160	INV2	Lc	A
	<i>Symphodus roissali</i>	0.0097	0.0099	0.0196	0.0183	0.0202	0.0156	INV2	Lc	A
	<i>Symphodus rostratus</i>	0.0008	0.0008	0.0057	0.0006	0.0034	0.0029	INV2	Lc	A
	<i>Symphodus tinca</i>	0.0302	0.0193	0.0233	0.0009	0.0368	0.0248	INV2	Lc	A
	<i>Thalassoma pavo</i>	0.0863	0.0999	0.0806	0.0901	0.1296	0.1073	INV2	Lc	A
Mullidae	<i>Mullus surmuletus</i>	0.0080	0.0043	0.0020	0.0015	0.0032	0.0013	INV2	Hc	A
Muraenidae	<i>Muraena helena</i>	0.0005	0.0010	0	0	0.0005	0.0005	LP	Lc	B
Pomacentridae	<i>Chromis chromis</i>	1.6448	1.2539	2.2295	2.5037	1.6164	1.1357	PLA	Nc	A
Rhinobatidae	<i>Rhinobatos rhinobatos</i>	0.0069	0.0120	0	0	0	0	LP	Hc	B
	<i>Epinephelus costae</i>	0.0023	0.0027	0.0011	0.0015	0.0045	0.0016	LP	Hc	B
	<i>Epinephelus marginatus</i>	0.0032	0.0014	0.0011	0.0015	0.0004	0.0004	LP	Hc	B
Serranidae	<i>Mycteroperca rubra</i>	0.0228	0.0387	0	0	0.0419	0.0726	LP	Hc	B
	<i>Serranus cabrilla</i>	0.0149	0.0137	0.0013	0.0006	0.0096	0.0090	SP	Lc	A
	<i>Serranus scriba</i>	0.0100	0.0099	0.0120	0.0018	0.0192	0.0015	SP	Lc	A
Sciaenidae	<i>Sciaena umbra</i>	0.0088	0.0135	0.0011	0.0009	0.0077	0.0125	LP	Hc	B
	<i>Scorpaena scrofa</i>	0.0074	0.0064	0.0027	0.0039	0.0018	0.0032	SP	Hc	C
Scorpenidae	<i>Scorpaena notata</i>	0.0005	0.0010	0	0	0.0037	0.0032	SP	Lc	C
	<i>Dentex dentex</i>	0.0025	0.0030	0.0052	0.0067	0.0001	0.0002	LP	Hc	B
Sparidae	<i>Dpilodus annularis</i>	0.1294	0.0336	0.1158	0.0300	0.0704	0.0662	INV2	Lc	A

	<i>Diplodus cervinus</i>	0.0016	0.0028	0	0	0.0020	0.0028	INV2	Hc	A
	<i>Diplodus puntazzo</i>	0.0053	0.0040	0.0142	0.0175	0.0096	0.0113	INV2	Hc	A
	<i>Diplodus sargus</i>	0.0225	0.0179	0.0515	0.0018	0.0257	0.0117	INV1	Hc	A
	<i>Diplodus vulgaris</i>	0.0829	0.0295	0.1387	0.1227	0.1023	0.0353	INV1	Hc	A
	<i>Boops boops</i>	0.1058	0.1230	1.5277	0.1964	0.0342	0.0550	PLA	Lc	A
	<i>Oblada melanura</i>	0.1131	0.0997	0.1004	0.0062	0.0768	0.0500	PLA	Lc	A
	<i>Sarpa salpa</i>	0.1362	0.0534	0.0973	0.0125	0.1102	0.0610	HERB	Lc	A
	<i>Sparus aurata</i>	0.0048	0.0031	0	0	0.0008	0.0011	INV1	Hc	A
	<i>Spicara maena</i>	0.1152	0.1064	0.1857	0.0207	0.0029	0.0051	PLA	Lc	A
	<i>Spicara smaris</i>	0.1277	0.1723	0.0071	0.0100	0.0035	0.0047	PLA	Lc	A
	<i>Spondylisoma cantharus</i>	0.0600	0.0440	0.1047	0.1431	0.0035	0.0061	INV2	Lc	A
Sphyraenidae	<i>Sphyraena</i> spp.	0.0262	0.0454	0	0	0.0069	0.0112	LP	Hc	B
Tripterigidae	<i>Tripterigion delaisi</i>	0.0018	0.0032	0.0027	0.0039	0.0425	0.0325	SCCB	Nc	C
	<i>Tripterigion tripterotonus</i>	0.0037	0.0064	0.0027	0.0039	0.0406	0.0705	SCCB	Nc	C

Supplementary material III.2.

Table III.6. Number of individuals for commercially relevant species as the total number in the three years per location (KU, Kuriat, CNCS Cap Negro Cap Serrat, TA: Tabarka), in unprotected and future protected areas

Zone	Un-protected			Future protected		
Location	KU	CNCS	TA	KU	CNCS	TA
<i>Coris julis</i>	119	98	316	286	110	320
<i>Dentex dentex</i>	1	11	1	5	1	0
<i>Diplodus annularis</i>	57	46	104	184	73	130
<i>Diplodus puntazzo</i>	3	4	26	33	60	39
<i>Diplodus sargus</i>	9	66	53	109	168	121
<i>Diplodus vulgaris</i>	60	154	185	155	102	506
<i>Epinephelus costae</i>	1	4	0	15	1	19
<i>Epinephelus marginatus</i>	0	5	1	22	0	2
<i>Mullus surmuletus</i>	18	0	13	36	9	9
<i>Sciaena umbra</i>	0	3	2	14	2	4
<i>Serranus cabrilla</i>	9	3	23	46	3	42
<i>Sparus aurata</i>	1	0	6	20	0	0



III.6. Supplementary material 3. Sampling sites in future MPAs

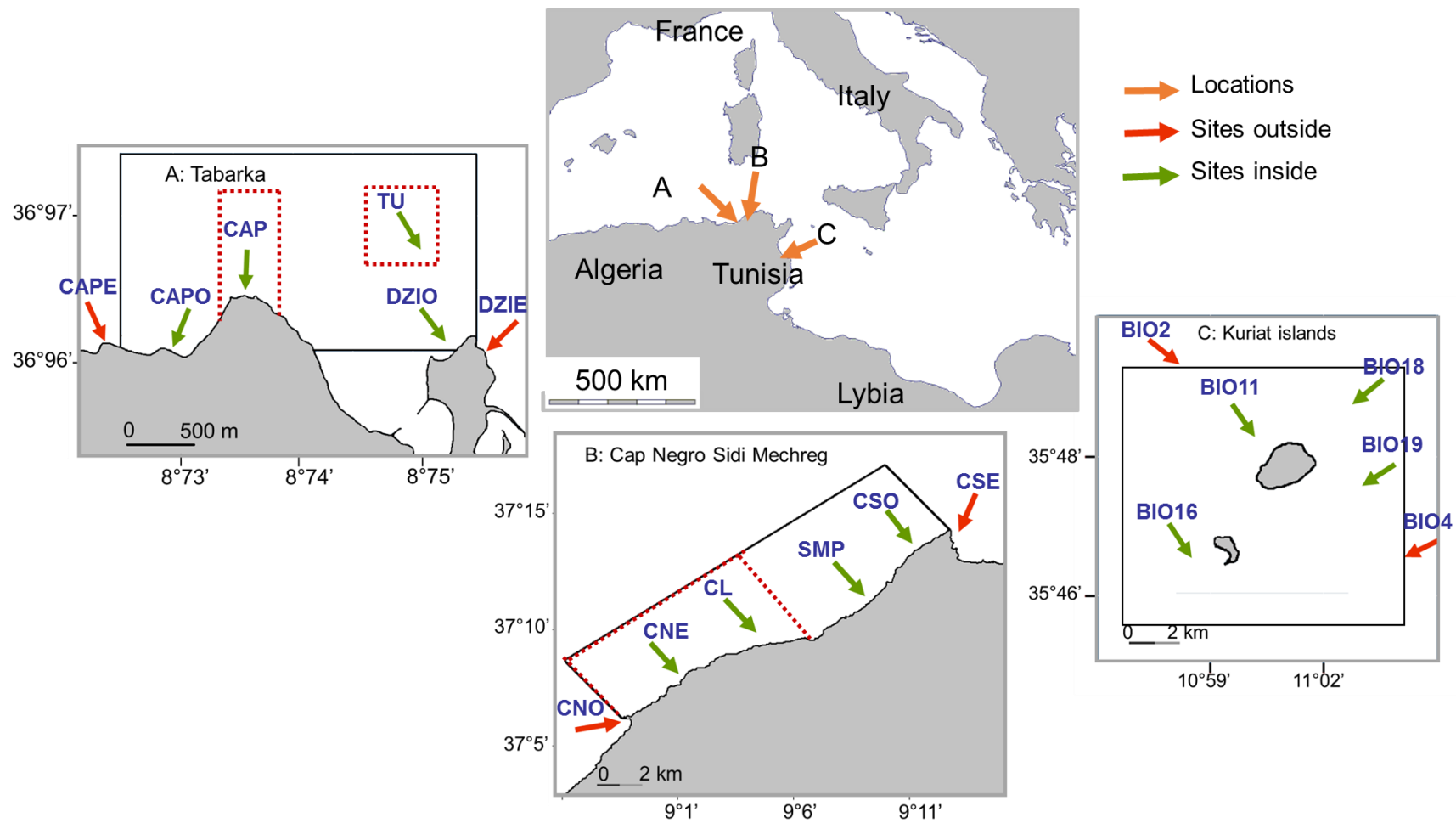


Figure III.6. Locations maps, black continuous lines are future MPA limits, dotted red lines presents proposed limits of no-take zones in management plans

*Chapter IV: Fish assemblage
monitoring by UVC in future
Tunisian MPAs: Challenges and
difficulties*

IV.1. UVC methods in Tunisian future MPAs: Who does what?

For most marine and coastal fish communities, a variety of survey methods exist. Given that survey results may be used for conservation and management decisions, it is therefore important to evaluate how different monitoring methods perform, and whether they can replace or complement each other (Murphy & Jenkins, 2010, Baker *et al.*, 2016). Concerning Tunisia, seven MPAs are planned to be implemented in the next future. Their management plans, zoning and restrictions to uses are still being discussed (Zarrouk, 2017; CAR/ASP & PNUE-PAM, 2014). Monitoring fish assemblages in Tunisian MPAs should begin at this stage. Fish monitoring using standard UVC methods needs highly skilled divers in fish species identification and a lot of training and calibrations dives (Prato *et al.*, 2016). Volunteer based monitoring programs are perceived as a cost-effective way to gather data efficiently in data poor regions.

Easy-to-use methods were proposed for target fish monitoring along French Mediterranean coasts. This method is based on presence/absence during 6 replicates of 15 min dive. Fish Assemblage Sampling Techniques (FAST) applied by volunteer divers could be an alternative solution to the lack of funds and data. Since FAST was developed for the north Mediterranean coasts (Seytre & Francour, 2008; 2009), an adaptation of this method was necessary to propose a new list of Tunisian fish species to monitor. Basing on published fish inventories in Tunisia (Bradai, 2000; Bradai *et al.*, 2004), a list of all Tunisian fish was established. Like the French FAST list, the Tunisian FAST list include all fish species that can be encountered between 0 and 20 meters depth, targeted by commercial small-scale (CSS) fisheries, spearfishing or angling, vulnerable and easy to identify in scuba diving, and representative species of the main coastal biocenosis (sand, rocky area covered or not by photophilic algae and seagrass) (Seytre & Francour, 2008; 2009). From the total Tunisian list of species, we only considered the species usually present in coastal zone between the surface and 20m depth. For each of these species the following criteria were scored (from 0 to 2, see supplementary material IV.2): endemism in Mediterranean Sea (0: non-endemic, 2: endemic), facility underwater identification, rarity, diet, high trophic level predators, longevity, hermaphroditism, targeted by fishing or not, vulnerability, non-indigenous species, and specificity toward habitat (see Table IV.1). Scores of top predators and fishing target took double of their

values. Fish species with a sum of score greater than 10 (value chosen as a threshold) were retained for the list.

Table IV.1. Scores corresponding to each criterion applied to establish FAST Tunisian list

Criteria	Value
endemism	0: not endemic, 2: endemic species
facility of underwater identification	0: not easy, 1: easy at genus level, 2: easy at species level
rarity	0: abundant, 1: less abundant, 2: rare
diet*	0: omnivores, 1: strictly herbivores or carnivores
high trophic level predators (HTLP)*	0: non HTLP, 1: HTLP
longevity	0 : from 1 to 7 years, 1: from 8 to 15 years, 2: from 16 to 50 years
hermaphroditism	0: non-hermaphrodite, 1: hermaphrodite
targeted by fishing or not	0: non-targeted, 1: targeted by one fishing type, 2: targeted by many fishing types
vulnerability**	0: not vulnerable, 1: vulnerable, 2: endangered
Lessepsian or Herculean species	0: no, 2: yes
specificity toward habitat*	0: no, 2: yes

*: criteria are considered from adult fish only.

** : according to IUCN

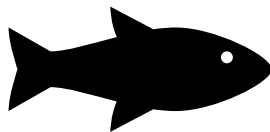
VI.2. Method deployment

Based on the pre-established list, the data acquisition consists of six replicates of 15-min visual censuses covering all kinds of substrata (sand, seagrass, rocky areas), along a random pathway using scuba diving. It is performed on a presence/absence and on a 2-size class basis (large fish, i.e. longer than 2/3 of the maximum size, and small/medium fish, smaller than 2/3 of maximum size). Maximum length of each species was obtained from fishbase.org. FAST indices were calculated, applying scores (S) to each species: S=1 for small/medium size individuals and S=2 for large ones. In addition, conservation coefficients are applied: some “key” species receive a higher conservation value ($\times 2$), both size classes included. We considered “key” species to be those with a high commercial value or those that were endangered (*Epinephelus marginatus*, *Epinephelus costae*, *Mycteroperca rubra*, *Phycis phycis* and *Sciaena umbra*). For other species, a single size class (the large

one) received the higher conservation value (*Dentex* spp., *Pagrus pagrus*, *Dicentrarchus labrax* and *Dasyatis pastinaca*). Seytre *et al.*, 2008, defined six indices to assess the fish assemblage health:

- The Mean Index (MI) was computed as the average of the 6 indices (one index for each 15-minute census). It can be used as a proxy for density of species and size-classes occurrence.
- The Cumulative Index (CI): it is computed following the same rules after pooling the six censuses together. CI can be interpreted as a proxy for species richness and size distribution.
- The Relative Species Richness (RSR) as the number of species observed among those listed.
- The carnivores index (CP): is determined as the proportion of species for which trophic level >3.7 (fishbase.org). Among the main list, eight species matched this criterion. However, except for the small/medium-sized groupers (*Epinephelus marginatus*, *E. costae* and *Mycteroperca rubra*), only large individuals were considered as carnivores. This criterion relies on the incapability of the smallest individuals to exert an actual predation role. CP was computed as the average number of observed carnivores among the carnivore list for a 15-minute census.
- The proportion of large individuals (LP) is the average number of large individuals among the species of the main list.
- A Coefficient of Variation (CV) is computed for the 6 indices (one for each 15-minute census). It allows to assess the fish assemblage spatial variability.

All indices are presented as a percentage of the maximum theoretical value, i.e. the value that would be obtained if all species and both size classes were observed in a 15-min visual census. In addition to these six indices, frequency of occurrences (the frequency of observation of each species (by size) in the six FAST replicates, expressed in percentage) were calculated (see Supplementary material IV.1)



Paper under review: Can citizen science contribute to fish assemblages monitoring in understudied areas? The case study of Tunisian marine protected areas, to Estuarine, Coastal and Shelf Science

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This manuscript is under review in Estuarine Coastal and Shelf Science

Manuscript number ECSS_2016_252

IV.3. Abstract

Resource monitoring is a key issue in ecosystem management. This is the case for marine protected areas (MPAs), where information on the composition and structure of fish assemblages is crucial to design a suitable management process. Data on fish assemblage is usually collected using underwater visual censuses (UVC). However, fish assemblages monitoring in MPAs usually calls for considerable resources in terms of costs, time and technical/ scientific skills. Financial resources and trained scientific divers may however not be available in certain geographical areas, that are thus understudied. Therefore, involving citizen volunteer divers in fish assemblage

monitoring and adopting easy-to-use underwater visual census methods could be an effective way to collect crucial data. Citizen science can be used only if it can provide information that is consistent with that collected using standard scientific monitoring. Here, we aim to 1) compare the consistency of results from a Standard scientific UVC (S-UVC) and an Easy-to-use UVC (E-UVC) method in assessing fish assemblage spatial variability, and 2) to test the consistency of data collected by Scientific Divers (SD) and scientifically-trained volunteer divers (STV), using E-UVC. We used, in two consecutive years, three Tunisian future Marine Protected Areas (MPAs) and adjacent areas as case studies. E-UVC and S-UVC data were consistent. The two methods reported the same spatial patterns for the three MPAs (between MPAs and, inside and outside each one), highlighting the consistency between S-UVC and E-UVC. No significant difference was recorded between data collected by SD or STV. Our results suggest that E-UVC can provide information representing simplified proxies for describing fish assemblages and can therefore be a valuable tool for describing fish assemblages and can therefore be a valuable tool for fish monitoring by citizen divers in understudied areas. This evidence could foster citizen science as an effective tool to raise environmental awareness and involve stakeholders in resource management.

IV. 4. Introduction

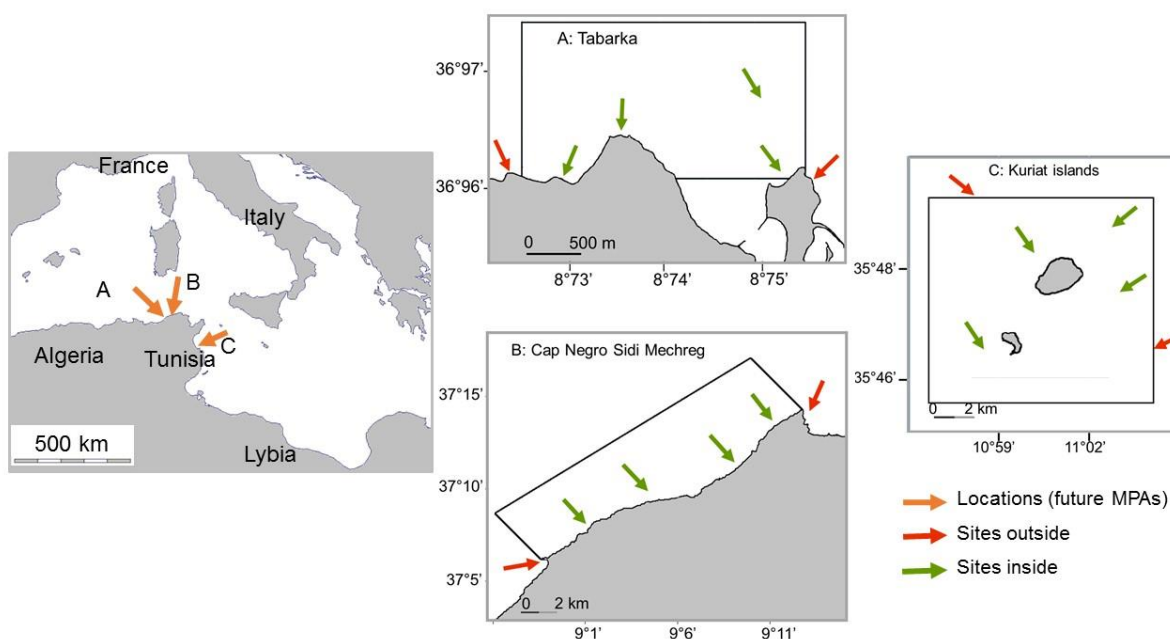
Marine protected areas (MPAs) are known as an important tool to protect coastal fish assemblages (Edgar *et al.*, 2014, Guidetti *et al.*, 2014, Mellin *et al.*, 2016), and to provide support for tourism and education (e.g. Fenberg *et al.*, 2012, Alós & Arlinghaus 2013, Marques *et al.*, 2013). In order to assess whether MPAs are achieving their conservation goals, and thus, their effectiveness, it is essential to monitor marine and coastal assemblages, especially those with high ecological and economic value. Therefore, data on the structure and composition of fish assemblages are of crucial importance. In several MPAs worldwide, scientists have performed monitoring of fish fauna using underwater visual census (UVC) counts (e.g. Bell 1983, Harmelin, 1987, Zabala 1990, Francour 1991, 1994, Harmelin *et al.*, 1995, Planes *et al.*, 2000, Dufour *et al.*, 2007, Sahyoun *et al.*, 2013, Seytre *et al.*, 2013, Edgar *et al.*, 2014, Seytre & Francour 2014). Standard UVC (S-UVC) along transects (most widely used (Prato *et al.*, 2017)) is a non-destructive method that has the advantage of providing exhaustive information on fish fauna (i.e. species

richness, density, size of individuals and biomass). On the other hand, S-UVC calls for considerable resources in terms of costs, time and technical/scientific skills (Samoilys & Carlos 2000). In several geographical areas, there is a lack of Scientist Divers (SD) to perform S-UVC surveys. These areas are therefore understudied. In order to bridge this knowledge gap, it is essential to involve non-scientist divers, such as recreational divers, in fish monitoring surveys. UVC along transects have been carried out by recreational divers in many MPAs throughout the world (Edgar *et al.*, 2014), but this required highly skilled volunteers and an extensive and time-consuming training in scientific monitoring (Edgar *et al.*, 2014, Aburto-Oropeza *et al.*, 2015). Regular fish monitoring in understudied areas is also restricted by the limited funds. This is the case in Tunisia (south-west Mediterranean Sea), where UVC along transects have been used by scientists to collect data (used as reference state) for the development of MPA management plans (i.e. the case of La Galite archipelago, Tabarka, Zembra archipelago and Kuriat islands). Unfortunately, because of the above-mentioned constraints, these data collection surveys were not replicated in time (Orueta & Limam 2008, Harmelin *et al.*, 2010, Ody *et al.*, 2010, Ramos Espla *et al.*, 2010). Involving Scientifically-Trained Volunteers (STV) in collecting data on marine biodiversity can represent a cost-effective way to fill spatial and temporal gaps in traditional monitoring programs. STV have so far participated in projects on climate change, invasive species, conservation biology, ecological restoration and water quality monitoring (Silvertown 2009). Networks of STV have the potential to play a useful role in observing biodiversity and species distribution over large spatial scales, enhanced by the new popularity of citizen science in ecology (Léopold *et al.*, 2009, Goffredo *et al.*, 2010, Raitsos *et al.*, 2010, Gillett *et al.*, 2011, Bird *et al.*, 2014, Bodilis *et al.*, 2014, Dennhardt *et al.*, 2015, Loss *et al.*, 2015). However, involving volunteer divers in fish assemblage monitoring surveys requires Easy-to-use UVC methods (E-UVC). There is thus a need for new monitoring methods, to support citizen involvement in fish assemblage monitoring programs (Silvertown, 2009, Dickinson *et al.*, 2012, Bird *et al.*, 2014). Such methods need to be adapted and standardized for non-scientist divers and should have low training requirements. The Fish Assemblage Sampling Technique (FAST) is an E-UVC method, designed for routine monitoring of coastal areas, and designed for citizen science. Indices calculated from data collected with FAST censuses may be used as proxies of variables describing the structure and composition of fish assemblages (e.g. species

richness, total density, total biomass). However, the consistency of data gathered through E-UVC (e.g. FAST) and S-UVC is still largely unexplored, and represents a crucial proviso to support the adoption of E-UVC and citizen science as tools for the collection of crucial data. In this context, the aim of this study is to test the consistency of fish-assemblage spatio-temporal variability data, resulting from two UVC methods (TVW and FAST), and to test the reliability of data collected by STV using FAST in three Tunisian Marine Protected Areas (MPAs). S-UVC along transects with variable width (TVW) was applied by the SD, and the E-UVC Fish Assemblage Sampling Technique (FAST) method was applied by both SD and STV.

IV. 5. Method

IV.5.1. Study Areas



15 Figure IV.1. Locations and study zones (separated with lines, limits of future MPAs are proposed in management plans)

Three future Tunisian MPAs and adjacent unprotected areas (hereafter called “locations”) were chosen as case studies: Tabarka is situated on the west coast of Tunisia and covers 327.855 ha, down to 40-m depth. Cap Negro Sidi Mechreg is located on the north Tunisian coast, covering 1 300 ha,

down to 45-m depth. Kuriat islands are located off the east coast of Tunisia, covering 19674 ha, down to 40-m depth.

IV.5.2. Sampling design and data collection

Sampling was conducted using two UVC methods by scuba diving (1) Easy-to-use method E-UVC: Fish Assemblage Sampling Technique (FAST) and (2) Standard method S-UVC: transects with variable width (TVW). For each location, four sampling sites were randomly selected inside the location and 2 sampling sites were selected outside. All sampling sites have similar characteristics in terms of habitat (70% rocky bottoms, with 30% *Posidonia* meadows) and depth (10 to 20 meters). Sampling was carried out in two consecutive years (2014 and 2015), during August-September.

While TVW was performed only by the Scientific Diver (SD), FAST was performed by both SD and 6 Scientifically Trained Volunteers (STV), at the same sampling sites. STV were briefly trained (3 days) by SD in fish identification underwater and in the FAST method. The same STV performed FAST censuses with the same SD at all locations for the 2 years.

IV.5.2.1. Transects with variable width (TVW)

Transects of three different widths were used for different fish categories, based on their mobility: (1) transect 35 m x 10 m for large mobile high trophic level predators, (2) transect 25 m x 5 m for necto-benthic fish (except high trophic level predators, censused in transect 35mx 10m), and (3) transect 10 m x 1 m for crypto-benthic fish (Prato *et al.*, 2017) (see the appendix for the species list). At each transect species and size classes were estimated and recorded using 2 cm precision. The use of transects with multiple widths has been shown to be more precise than transects with single width in estimating large-sized and/or highly mobile species density (Prato *et al.*, 2017). At each site, the total density was calculated as the sum of standardized values (to the square meter) for each of the three transects. The same computation was applied for total biomass and total species richness. We also calculated Carnivores Proportion (*CP*) as the percentage of carnivores in density and Proportion of Large sized individuals (*LP*) as the percentage of large individuals in density (i.e. longer than 2/3 of the maximum size of each species) (fishbase.org).

IV.5.2.2. Fish Assemblage Sampling Technique (FAST)

For each sampling site, the data collection consists of six replicates of 15 minutes carried out between 10 and 20 m depth, along a random pathway using scuba diving. At each replicate, we considered: -the presence/absence of fish species from a pre-established list (not all the species were counted), and - their size-class (two classes were considered: large fish, i.e. longer than two-thirds of the maximum size for each species, and small fish, shorter than two-thirds of maximum size) (for a detailed description of the method see Seytre & Francour, 2008, 2009). The pre-established list includes species that are targeted by professional and/or recreational fishers (e.g. net fishing, spear-fishing or angling) (Table IV.1). For each replicate, an index (I) was calculated by summing coefficients for each species censused, related to the presence/absence of large-sized individuals and to the characteristics of some “key species” (vulnerability and/or high economic value). For each species, a coefficient of 2 was assigned if a large individual was censused. For small-sized individuals censused, a coefficient of 1 was assigned. Key species always received a coefficient of 2, related to the size, in addition to a coefficient of 2 assigned for their conservation value. Based on the 6 replicates, four indices were calculated as proxies of structure of fish assemblages: The Mean Index (*MI*; arithmetic average) was calculated from the six indexes I (from the six replicates), the proportion of Large sized individuals. Large Proportion (*LP*), displayed the proportion of the Large size individuals observed in the same census. In addition, the relative species richness (*RSR*) was calculated as the average number of species present. We also computed Carnivores Proportion (*CP*) as the average number of observed carnivore species. Only large individuals with trophic level > 3.7 were considered as carnivores (based on the trophic classification in Karpouzi and Stergiou 2002), except for the small-sized grouper (*Epinephelus marginatus*, *E. costae*, *Mycteroperca rubra*, considered as carnivores (Fishbase.org)).

Table IV.2. List of species monitored using FAST, with information on diet and habitat. For some species or size classes, a conservation value (x2) and a trophic value (x2) are used to weight the initial value (Small=1, Large=2). The coefficient applied on each species and size class is given for the conservation value (i.e. the computation of the *MI*) and the trophic value (i.e. the computation of *CP*), s: small, L: large. Diet of large size class individuals: H: herbivorous, O:

omnivorous, C: carnivorous, Habitat: R: rock, P: *Posidonia* meadows, S: sand, O: open water, C: caves

Taxon	Conservation value	Trophic value	Diet	Habitat
<i>Diplodus annularis</i>			O	R, P
<i>Diplodus cervinus</i>			O	R
<i>Diplodus puntazzo</i>			O	R
<i>Diplodus sargus</i>			O	R
<i>Diplodus vulgaris</i>			O	R
<i>Dentex</i> spp.	L		C	R
<i>Pagrus pagrus</i>	L		C	R
<i>Sarpa salpa</i>			H	R,P
<i>Lithognathus mormyrus</i>	L		O	S
<i>Spondylisoma cantharus</i>			O	R
<i>Serranus scriba</i>			C	R
<i>Serranus cabrilla</i>		L	C	R
<i>Epinephelus marginatus</i>	s, L	s, L	C	R
<i>Epinephelus costae</i>	s, L	s, L	C	R
<i>Mycteroperca rubra</i>	s, L	s, L	C	R
<i>Labrus</i> spp.			O	R, P
<i>Phycis phycis</i>	s, L	L	C	C
<i>Conger conger</i>		L	C	C
<i>Muraena helena</i>		L	C	C
<i>Seriola</i> spp.		L	C	O
<i>Sciaena umbra</i>	s, L	L	C	R, C
<i>Scorpeana scrofa</i>		L	C	R

<i>Sphyraena</i> spp.		L	C	O
Mugilidae			M	S
<i>Dicentrarchus labrax</i>	L	L	C	R
<i>Pomatomus saltatrix</i>	L	L	C	O
<i>Dasyatis pastinaca</i>	L	L	O	R, P

IV. 5.2.3. Data analyses

IV. 5.2.3.1. Consistency between data collected with TVW and FAST

In order to assess whether the two methods considered, consistently describe fish assemblage variability between locations and zones, we used four indices for FAST (the Mean Index (*MI*), the Relative Species Richness (*RSR*), Large Proportion (*LP*) and Carnivores Proportion (*CP*)) and four variables for TVW (total density (*DEN*), Species Richness (*SR*), Large Proportion (*LP*) and carnivores proportion (*CP*)). Respectively, each FAST index was taken as proxy for one of the variables from TVW.

The four indices were separately analyzed using resemblance based on Euclidean distance. In total, eight matrixes were created, each composed of one variable or index and n=269 samples. All matrixes were analyzed using 3-way permutational multivariate analysis of variance (PERMANOVA) (Anderson 2001). “Location” (random, 3 levels: Kuriat islands, Cap Negro Sidi Mechreg and Tabaraka), “Zone” (fixed, 2 levels: outside and inside locations), and “year” (random, 2 levels: 2014 and 2015). We used MonteCarlo permutations to estimate p values whenever the number of possible permutations was <200. The PRIMER 7 and PERMANOVA + package was used to perform the analyses.

IV. 5.2.3.2. Comparison between Scientific Diver (SD)-FAST indices and Scientifically Trained Volunteers (STV)- indices

FAST indices were used for comparison between the two groups: SD and STV data. Permanova was performed on four matrixes composed of one index each, and n=60 samples

corresponding to FAST samples of the two groups. All matrices were analyzed using 4-way permutational multivariate analysis of variance (PERMANOVA) (Anderson, 2001). Two fixed factors were used: “Group” (2 levels: SD and STV) and “Zone” (2 levels: outside and inside locations). Factors “location” (3 levels: Kuriat islands, Cap Negro Sidi Mechreg and Tabaraka) and “year” (2 levels: 2014 and 2015) were considered as random. We used MonteCarlo permutations whenever the number of possible permutations was <200 . The PRIMER 7 and PERMANOVA + package, were used to perform the analyses.

IV. 5.3. Results

IV. 5.3.1. Comparison between Locations using TVW and FAST (SD)

Permanova displayed the absence of significant difference for *SR*, *RSR* and *CP* (TVW, FAST) between locations, zones and years (Table IV.2 and IV.3). Interactions were not significant either for these variables. However, there was significant difference for density (*DEN*) at different locations, but not between zones. Interactions were not significant for this variable (Table IV.2). However, for *MI*, interaction between location and year was significant, while no significant differences were recorded for the other factors and interactions. *LP* calculated from TVW showed significant differences in interactions between location, zone and between location, year, but not between factors. *LP* calculated from FAST also displayed the same pattern as *LP*-TVW, but with one significant difference in the interaction between location, year. The TVW method can be more discriminatory in detecting differences in size estimation than the FAST method.

Table IV.3. Permanova used on TVW-data resemblance matrix. Density (*DEN*), Species Richness (*SR*), Carnivores proportion (*CP*) and Large Proportion (*LP*). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. lo: location; Zo: zone; ye: year.

TVW	Variables	DEN		SR		CP		LP	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
lo	2	0.51	798.57*	160.79	29.53	0.01	0.62	546.23	2.21
zo	1	0.17	0.75	42.25	0.43	0.003	0.62	58.51	0.62

ye	1	0.05	91.75	342.25	62.86	0.01	0.54	55.39	0.22
loxzo	2	0.29	9.69	91.64	2.28	0.03	1.03	85.57	1952100***
loxye	1	0.0006	0.006	5.44	0.36	0.02	0.64	246.1	4.51
zoxye	1	0.0007	0.02	96.69	2.41	0.02	0.71	16.93	386240***
loxzoxye	1	0.03	0.3	40.11	2.67	0.02	0.71	4.38E-05	0.000008
Res	80	0.09		15.00		0.04		54.46	
Total	89								

Table IV.4. Permanova used on FAST-data resemblance matrix. Mean Index (*MI*), Relative Species Richness (*RSR*), Carnivores proportion (*CP*) and Large Proportion (*LP*). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. lo: location; Zo: zone; ye: year.

FAST	Indices	MI		RSR		CP		LP	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
lo	2	757.76	3.16	2.22	0.10	25.22	1.25	93.279	0.92
zo	1	770.98	3.07	144.03	1.71	22.96	0.55	1.0432	0.66
ye	1	4.36	0.01	124.03	6.02	9.38	0.46	8	0.07
loxzo	2	222.71	5.66	64.75	2.25	48.33	17.75	9.7234	1.32
loxye	1	239.67	6.99**	20.58	2.14	20.05	3.35	100.35	34.08***
zoxye	1	63.70	1.62	41.25	1.43	2.72	1	2.7222	0.37
loxzoxye	1	39.28	1.14	28.75	3.00	2.72	0.45	7.35	2.49
Res	170	34.26		9.57		5.9814		2.9439	
Total	179								

IV. 5.3.2. Comparison between Scientific Diver (*SD*) and Scientifically Trained Volunteers (*STV*) FAST indices

Boxplots and Permanova showed no significant difference between groups for all indices (figure IV.2, Table IV.4). Interactions between factors were not significant for all indices except for *RSR* (factors group (*gr*) and location (*lo*)), and for *LP* (factors *gr* and *lo*, and *gr*, *lo* and zone (*zo*)) (Table IV.4). A significant difference in *RSR* between groups at Cap Negro Sidi Mechreg was highlighted, as well as for *LP* at Cap Negro Sidi Mechreg and Kuriat Islands.

Table IV.5. Permanova used on FAST-data resemblance matrix. Mean Index (*MI*), Relative Species Richness (*RSR*), Carnivores proportion (*CP*) and Large Proportion (*LP*). * $p < 0.05$; gr: group lo: location; zo: zone; ye: year.

FAST indices		MI		RSR		CP		LP	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
gr	1	5.13	0.66	161.67	0.69	430.44	2.29	50.11	1.01
lo	2	142.45	1.38	555.3	5.33	297.87	1.37	87.133	1.08
zo	1	8.4	0.45	35.842	2.46	30.803	0.30	19.362	0.72
ye	1	3.61	0.03	603.71	5.79	13.132	0.06	3.9384	0.05
grxlo	2	8.75	11.26	255.29	198.51*	61.021	0.58	54.146	6063*
grxzo	1	3.68	4.16	0.53764	1.09	0.35709	1.36	14.693	4.33
grxye	1	1.01	1.30	7.0016	5.44	174.24	1.66	1.5093	169*
loxzo	2	33.9	3.30	87.402	0.30	40.9	1.08	29.349	5.25
loxye	1	103.22	1.92	104.17	0.70	216.74	5.10	80.599	1.25
zoxye	1	8.54	0.83	41.29	0.14	177.18	4.67	7.5106	1.34
grxloxzo	2	0.74	13.91	1.56	1.22	0.94239	0.50	3.723	416.88*
grxloxye	1	0.77	0.01	1.28	0.008	104.58	2.46	0.00893	0.001
grxzoxye	1	0.22	4.27	0.14	0.11	0.6422	0.34	0.08038	9
loxzoxye	1	10.24	0.19	289.35	1.95	37.871	0.89	5.5816	0.08
grxloxzoxye	1	0.05	0.001	1.28	0.008	1.8656	0.04	0.00893	0.001
Res	40	53.515		148.13		42.437		64,251	
Total	59								

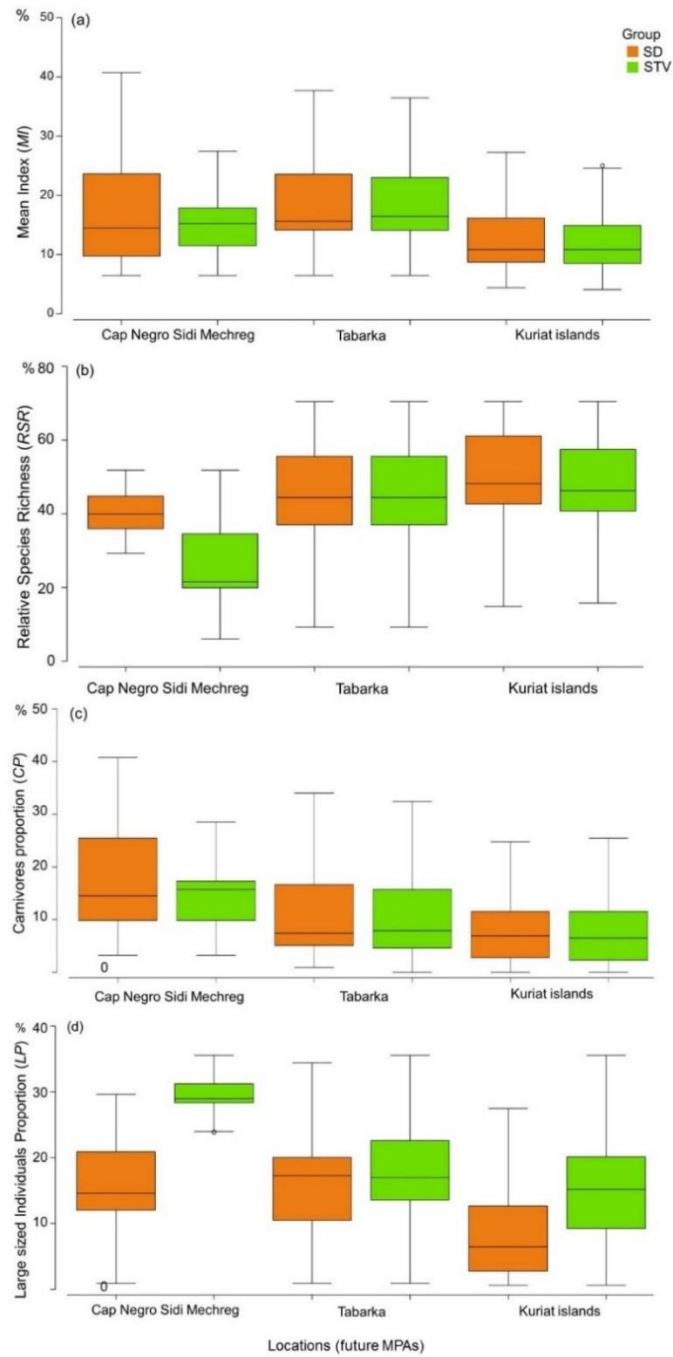


Figure IV.2. Boxplots of FAST indices, (a) Mean Index (*MI*), (b) Relative Species Richness (*RSR*), (c) Carnivores Proportion (*CP*) and (d) proportion of large sized individuals (*LP*), calculated from Scientific Diver (SD) and Scientifically Trained Volunteers (STV) observations.

IV.5.4. Discussion

Resource monitoring is a major issue in marine and coastal areas management, especially when it comes to MPAs where fish assemblage monitoring is essential. Underwater visual census is the most effective method for fish scientific monitoring in MPAs (Harmelin-Vivien *et al.*, 1985, Francour, 1997). Standard UVC (S-UVC) surveys along transects provide exhaustive information regarding fish assemblages (species richness, density, size and biomass). They also require a considerable effort in terms of costs, time and scientific skills (Samoilys & Carlos 2000, Edgar *et al.*, 2014, Aburto-Oropeza *et al.*, 2015). In understudied areas, regular fish monitoring, using S-UVC methods, is constrained by the limited number of local Scientific Divers (SD) and by the limited funds. Involving Scientifically Trained Volunteers (STV) in fish assemblage monitoring may be of interest in these areas, but requires Easy-to-use UVC methods (E-UVC) that are pertinent and low-cost in terms of training requirements.

In this study, our aim was to test the consistency between an S-UVC method (transects with variable width, TVW) and an E-UVC method (Fish Assemblage Sampling Technique, FAST). We also tested the consistency of data collected by volunteer divers (STV) with scientific monitoring using the FAST method. TVW, like most exhaustive visual census methods, needs to be performed by well-trained SD (Aburto-Oropeza *et al.*, 2015, Pelletier *et al.*, 2011), because all encountered fish are counted and their size estimated precisely (e.g. using 2 cm precision). FAST fish species are easy to identify, and some species, for which confusion in identification could arise, were grouped together at the genus level (e.g. *Labrus viridis* and *Labrus merula* merged as *Labrus spp.*), so divers do not need extensive training to be able to apply this method correctly.

Results for fish assemblage spatio-temporal variability at different locations between TVW and FAST (scientific observation only) displayed a similar pattern, with no significant difference between locations, zones or years. Differences in interactions between factors were detected for density and Mean index, as well as for Large Proportion. Considering the difference in size estimation between the two methods, TVW, where size is estimated to 2 cm precision, can detect changes in fish communities more precisely. For the other variables/indices, we consider that the two methods were generally consistent in terms of results. This coherence between patterns led us

to consider that information provided by FAST (simplified proxies) would be suitable for use in describing fish assemblages in the three-studied future MPAs, before enforcement of the protection regulations. Once these future MPAs benefit from effective protection, FAST proxies should be experimented with TVW variables, to test whether they detect positive effects of protection or not. Further investigations in other understudied and studied regions are also needed to provide more extensive evidence.

The comparison between SD and STV FAST data showed no significant difference in 3 indices. The same STVs carried out FAST censuses at the three locations. STVs had no difficulty in identifying species underwater and noted the presence of the same species as the SD. A significant difference was highlighted for Large Proportion index at two locations out of three. Before the fish census, volunteer divers received training in the FAST method. Although the training was effective for learning the technique and species identification, the size estimation of fish underwater remains a problem for many observers. For this reason, information about size should be interpreted with caution when non-scientific divers collect the data. Furthermore, regular training for the estimation of the size should be recommended for all the observers. These results suggest that FAST may be a valuable tool for fish monitoring by STV divers in understudied areas, where difficulties in rigorous assessment using standard methods are emerging (lack of scientific divers and lack of funds). The use of FAST should be always preceded by proper coaching and followed by scientific validation.

Stakeholder commitment has been highlighted as a crucial issue to collect data, manage and make decisions regarding the future of marine resources (Di Franco *et al.*, in press, Gopnik *et al.*, 2012, Pomeroy and Douvere 2008). STV contribution in the monitoring of future MPAs in Tunisia seems to be reliable, but must be regularly validated by scientists. In addition, it is very important to inform participants of the results of the sampling by sharing reports or presentations with them, to highlight the importance of their efforts and their contribution to the scientific monitoring process. This kind of involvement increases their awareness and sense of commitment to MPAs (Conrad & Hichely 2011, Bodilis *et al.*, 2014, Denhart *et al.*, 2015, Goffredo *et al.*, 2010).

Our work has assessed the reliability of information collected through citizen-science to implement the monitoring of fish populations. Even if the monitoring approach involving non-

scientist divers using the FAST method has only proxies for variables as results, it can be of value for developing, in the future, large-scale monitoring in the Tunisian MPAs. The integration of citizen science data within scientific monitoring programs is now acknowledged as an effective strategy (e.g. Azzuro *et al.*, 2013, Bodilis *et al.*, 2014, Dennhardt *et al.*, 2015 and references within, Dickinson *et al.*, 2012, Goffredo *et al.*, 2010). In the case of Tunisia, a significant benefit of this approach is that long-term fish assemblage monitoring can be undertaken at relatively low cost.

IV.5.5. Conclusion

The TVW method is exhaustive. However, it requires time to achieve sufficient spatial and temporal replication and regular training of participants. Ideally, when possible, it should be performed by scientist divers in order to have reliable and exhaustive variables. On the other hand, FAST is an E-UVC method, providing proxies on the fish assemblage whenever it is not possible to achieve S-UVC. It can be carried out by volunteers after training to become familiar with species and size estimation. Under scientific validation and coaching, this method can be used routinely in the case of Tunisia (MPAs and elsewhere). This citizen-science experiment would appear to be of value as a basis for the implementation of a long-term survey of fish assemblages along the Tunisian coasts. A monitoring program of this kind would increase the interaction between the public and the scientific community, and increase awareness regarding ecosystems and resource management.

Financial support

This paper is part of the Ph.D. thesis of Emna Ben Lamine. This work has received funding from the MedMPAnet Project (coordinated by the RAC/SPA), the Agence de Protection et d'Aménagement du Littoral (APAL), the association Abyse Plongée (Tunisia) and the Agence de l'Eau Rhône-Méditerranée-Corse (France).

Acknowledgments

The authors gratefully acknowledge the help of Ms Catherine Seytre and Ms Claudia Scianna, for their valuable contribution. STV FAST censuses were carried out with the scientifically trained volunteer divers: Sofiéne Ben Aissa, Mourad Saidane, Oussema Ben Lamine, Raja Ben Aissa, Omar Ben Hassine, Slim Souihi, under the supervision of scuba diving instructors Mahdi Aguir, Wissem

Houiji and Abderrahmane Mliki. The diving equipment was partially provided by the company Aqualung.

Supplementary material 1:

Table IV.6. species monitored by transect with variable width

Transect 10m x 1m: Cryptic species' category including families of:

Blennidae

Gobidae

Scorpaenidae

Trypteriglidae

Transect 35m x 10m: High trophic level predators' category (*species used to compute Carnivores Proportion (CP))

*Dentex dentex**

*Dicentrarchus labrax**

*Epinephelus costae**

*Epinephelus marginatus**

*Mycteroperca rubra**

*Pagrus pagrus**

*Sciaena umbra**

Sphyræna sp.*

Transect 25m x 5 m: necto-benthic species' category

Apogon imberbis

Boops boops

Chromis chromis

Conger conger

Coris julis

Diplodus annularis

Diplodus puntazzo

Diplodus sargus

Diplodus vulgaris

Labrus merula

Labrus viridis

Liza sp.

Mugil sp.

Mullus surmeletus

Muraena helena

Oblada melanura

Pagellus sp.

Sarpa salpa

Serranus cabrilla

Serranus scriba

Sparus aurata

Spicara sp.

Spondylisoma cantharus

Symphodus spp.

Thalassoma pavo

Trachurus sp.



IV.6. Supplementary material 2: STV improving in UVC methods

In 2014 and 2015, at all locations, UVC results were compliant with FAST ones. Then, FAST SD and FAST STV indices were not significantly different, except LP. To remediate to the problem of size estimation, more effort was concentrated to calibrate estimations by STV. Therefore, a printed board was used with all fish species pictures with size limits for small and medium classes (see appendix IV.2). Then, using the same sampling scheme, UVC using FAST (SD and STV) and transects (SD) with variable width were carried out in the same three locations (Kuriat islands, Cap Negro Cap Serrat and Tabarka) during the warm season in 2016. Data collected were added to the previous data (2014 and 2015) and data analysis was performed on the total collected data. Using the same data analysis scheme, we looked for significant difference between zones using indices and variables (table IV.5 and table IV.6). FAST-SD and FAST-STV were also compared using the same factors (table IV.7).

Table IV.7. Univariate Permanova used on TVW-data resemblance matrix. Density (*DEN*). Species Richness (*SR*). Carnivores proportion (*CP*) and Large Proportion (*LP*). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. lo: location; Zo: zone; ye: year.

TVW	Variables	Den		SR		CP		LP	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
Lo	2	4080.9	2.08	3179.3	11.22*	16.13	0.81801	2146.3	2.92
zo	1	3313.2	0.72	419.03	0.32	9.15	0.56	150.77	1.41
Ye	2	6205.8	3.17	3077	10.85*	103.54	5.25*	2160.1	2.93
loxzo	2	4296.2	12.23*	1328.7	6.92	53.9	1.16	61.372	0.32
loxye	3	1954	2.49*	283.35	1.26	19.72	0.67	735.04	4.44**
zoxye	2	951.18	2.70	583.92	3.04	40.84	0.88	179.52	0.93
loxzoxye	3	351.27	0.44	191.78	0.85	46.27	1.59	191.17	1.15
Res	128	781.62		224.29		29.07		165.5	
Total	143								

Table IV.8. Univariate Permanova used on FAST-data resemblance matrix. Mean Index (*MI*). Relative Species Richness (*RSR*). Carnivores proportion (*CP*) and Large Proportion (*LP*). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. lo: location; Zo: zone; ye: year.

FAST	Indices	MI		RSR		CP		LP	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
lo	2	7768.1	1.69	2033.8	1.58	9.29	0.47	76.39	1.1
zo	1	4570.3	0.58	1192.2	0.48	30.23	0.42	1.73	0.13
ye	2	17708	3.87	6786.3	5.27	118.18	6	145.34	2.1
loxzo	2	8680.1	8.02	5255.2	3.4	72.75	77.80**	23.492	8.28
loxye	3	4570.6	14.12***	1286	5.06***	19.68	4.64**	69.02	33.33***
zoxye	2	1186.9	1.09	356.54	0.23	4.14	4.42	9.59	3.38
loxzoxye	3	1081.6	3.34*	1545.7	6.08***	0.93	0.22	2.83	1.36
Res	272	323.5		254.13		4.24		2.07	
Total	287								

Overall, using TVW, SR and CP showed significant difference for the factor year. Interactions location x zone was significant for density and interactions location x zone and location x year were also significant for LP. All other factors and interaction were not significant.

Concerning FAST, the interaction location x zone x year was significant for MI and RSR. Interaction location x year also significant for all indices. Interaction location x zone was also significant for CP. All other factors and interactions were not significant.

The overall location/zone patterns described using TVW was similar to the one described by FAST. These results are in agreement with the previous results (2014 and 2015). This suggest the reliability of FAST method (easy-to-use) and its complementarity with TVW (standard method), in data poor regions.

Table IV.9. Univariate Permanova used on FAST-data resemblance matrix. Mean Index (*MI*), Relative Species Richness (*RSR*), Carnivores proportion (*CP*) and Large Proportion (*LP*). * $p < 0.05$; gr: group lo: location; zo: zone; ye: year.

FAST indices		MI		CI		RSR		CP		LP	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
Gr	1	4.32	2.49	27.97	2.95	246.93	2.40	14.51	4.46	133.92	0.54
Lo	2	53.67	0.48	19.64	0.12	691.58	2.51	19.92	0.20	275.66	2.47
Zo	1	0.16	1.16	18.99	1.31	72.18	3.19	9.42	2.08	69.78	0.61
Ye	2	627.85	5.62	1345.6	8.26	644.06	2.34	501.75	5.12	2208.6	19.84*
grxlo	2	1.73	0.08	17.47	0.43	98.24	0.77	8.62	0.18	111.3	4.12
grxzo	1	6.24	1.27	7.73	0.66	23.06	1.11	11.04	0.90	36.59	0.44
grxye	2	8.02	0.38	5.46	0.13	59.18	0.46	4.95	0.10	10.65	1.62
loxzo	2	8.94	0.30	72.67	0.66	28.77	0.19	5.76	0.18	366.21	4.42
loxye	3	111.65	3.15*	162.86	2.90*	274.62	2.33*	13.13	0.42	41.86	2.00
zoxye	2	15.61	0.52	21.54	0.19	40.08	0.26	97.84	2.31	108.82	5.20
grxloxzo	2	10.01	1.26	65.23	1.15	108.92	0.65	12.54	2.92	8.49	0.97
grxloxye	3	20.72	0.58	28.28	0.49	56.079	0.33	47.52	1.12	3.52	0.40*
grxzoxye	2	1.02	0.12	40.23	0.71	151.29	1.28	4.80	1.11	82.77	3.06
loxzoxye	3	29.61	0.83	108.54	1.93	126.97	1.07	30.95	0.73	20.89	0.77
grxloxzoxye	3	7.90	0.22	56.68	1.01	167.14	1.41	4.29	0.10	8.73	0.32
Res	64	35.37		56.00		117.77		42.28		27.00	
Total	95										

Comparison between FAST-SD and FAST-STV showed only significant interactions ‘group x location x year’, and significant factor year for LP. Significant interaction location x year was also significant for indices MI, RSR and CP. All other factors and interactions were not significant. There was not significant difference for factor ‘group’ for all indices. Contrarily to results presented previously, there was not significant difference between LP-SD and LP-STV in 2016. This shows the efficiency of training and calibrations. The use of FAST by volunteer divers is therefore suggested here as a cost-effective way to collect useful information about target fish species. Monitoring of fish assemblages in Tunisia can be performed by scientists and volunteer divers after trainings and calibration dives. This collaboration is needed to raise awareness among citizens divers especially in MPAs contexts.

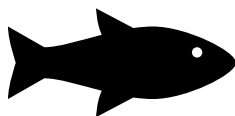
The most concerning pressures to MPAs regarding extent and intensity were: climate change, fishing and pollution from maritime transport (Rodríguez-Rodríguez *et al.*, 2015). Moreover, the lack of data on the pressures is to be considered, especially in offshore areas and in southern Mediterranean countries and ecoregions (Micheli *et al.*, 2013). MPA management can be effective at dealing with important local pressures such as fishing pressure through proper regulation, governance and enforcement (Micheli *et al.*, 2013).

In Tunisia, CSS fishing sector is well-developed and offers job to many households. CSS fishing is using a wide variety of passive gears to get multispecies catch. Romdhane, 1998, listed a variety of ‘artisanal’ (or ancestral) techniques. They can be fixed (such as ancestral technique “Charfia” used in Kerkennah Islands (south Est of Gabes Golfe)), where the gear is used as a trap and the fishermen come and empty the “trap chamber”. Other passive techniques are also used (such as longline, pots, trammel nets, “invisible” nets, “Coryphaena Seine”, ... etc.). It is an activity that is endangered by the industrialization of fishing and by the rarity of demersal fish stocks due to overexploitation in Tunisian shallow coastal waters (Halouani *et al.*, 2015). CSS fleets presents 80% of the total Tunisian fishing fleet, but produces only 25% of national fishing production (official statistics of the Ministry of Agriculture, 2015). CSS fishing sector in Tunisia is also suffering from some problems, for instance, the bad status of the boats, the illegal fishing and the overexploitation of demersal and benthic stocks (DGPA, 2016).

Monitoring of fishing activities in Tunisia is hampered by the high distribution of ports (84 ports all along Tunisian coasts) and by the authorized mobility of fishing activity. According to the strategy of creating MPAs all along coasts (Zarrouk, 2017), CSS fishing activity is expected to get benefits from protection. Thus, MPAs are implemented to protect resources, but also to enhance local economic activities such as CSS fishing.

*Chapter V: Assessing coastal
fishing (1): toward a better
understanding of ecological
and socio-economic attributes
of coastal fishing in Tunisia*

Results of UVC methods (standard and easy-to use) showed a poor fish assemblage with dominance of planktonivores and small and medium size classes. Densities and biomass were also comparable to other fished Mediterranean areas. UVC method used (TVW) is exhaustive, quantitative and repeatable. It has minimal impact on the environment. However, all UVC methods have also biases in size estimation due to the air-water interface in the diver mask (leads to size magnification (though methods exist to standardize size estimates)). Species behavior (escape or attraction response of fish resulting respectively from overfishing or underwater feeding by recreational divers) may also affect the results (Baker *et al.*, 2016). Also, in turbid waters with low visibility, UVC may result in reduced observations and consequently underestimation of faunal abundance and richness. A complementary approach to fish assemblage monitoring methods by UVC can be fishing monitoring methods (Backer *et al.*, 2016). Monitoring by fishing gears (as trammel nets) can be useful in showing cryptic and nocturnal species that are not visible using visual census technique during the day.



Paper under review: Investigating small-scale coastal fisheries (commercial and recreational) and their competition with illegal fishing as a crucial step for Marine Protected Areas management: a survey from the southern Mediterranean Sea, **Submitted to Fisheries Management and Ecology**

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Key words: small scale fishing, seasonality, mean catch, trophic level, Tunisia

V.1. Abstract

Commercial small-scale (CSS) fishing in the Mediterranean Sea accounts for more than 80 % of the commercial fishing fleet. CSS fishing competes (in terms of fishing resources and maritime space) with emergent non-professional fishing categories, such as recreational (REC) and illegal fishing (IF). Fisheries statistics usually fail to report non-professional fishing data, including those related to illegal fishing. The aim of this study is to investigate the potential competition between different fishing categories (CSS, REC and IF) and their temporal variability in two areas in Tunisia designated as Marine Protected Areas (MPAs). During a two-year sampling campaign, 213 small-scale coastal fisheries landings (CSS, REC and IF) were monitored. Additional socio-economic information was also collected by means of direct questionnaires. Catch composition, mean catch, catch trophic level, vulnerability of species fished, their commercial value in local markets and the size-frequency distribution of four fish species of high commercial value, were calculated and compared between fishing categories. Results highlighted that: (1) at least 47.91% of non-professional fishers declared fishing as their primary occupation and admitted selling the catch (and so are classified as illegal fishers), (2) IF and REC fishing mean catch per fishermen per day (MC), represented, respectively, 40% and 20% of that of CSS fishing, (3) mean catch and species richness for IF and CSS followed the same temporal patterns at both locations, (4) all fishing categories had caught high trophic level and vulnerable species, and (5) IF and REC catch selling prices were significantly higher than those of CSS catches. These findings are among the first to provide quantitative direct evidence of close competition between IF and legal fishing (CSS and REC) in Mediterranean Sea. Results also highlight the need for effective enforcement to combat IF, and the importance of taking into account REC and IF in fisheries and MPA management planning.

Key words: fish; professional; illegal; legal; Tunisia

V.2. Introduction

Small-scale coastal fishing, including Commercial Small-Scale (CSS), recreational and subsistence fishing, or a combination of the above (Lloret *et al.*, 2016), plays a crucial role in local and national socio-economic development in many countries (Arlinghaus *et al.*, 2002; Cowx, 2002; Hilborn *et al.*, 2003; Halpern *et al.*, 2008), including those located around the Mediterranean Sea (FAO, 2016). CSS fishing is a professional activity usually associated with small boats, of low tonnage, using generally passive fishing gear with short duration outings. CSS fisheries account for

more than 80% of the professional Mediterranean fishing fleet (FAO, 2016). They require low capital investment. They use a wide range of fishing gear, allowing multi-specific and seasonal catches (Farrugio *et al.*, 1993; Freire and Garcia-Allut, 2000; Forcada *et al.*, 2010; Guyader *et al.*, 2013; Halouani *et al.*, 2015). On the other hand, the increase in human populations inhabiting coastal areas can contribute to an increase in the practice of recreational fishing, recognized as one of the most common leisure activities (Arlinghaus *et al.*, 2002, Venturini *et al.*, 2017). Recreational fishing (REC) is defined as all fishing activities that are not conducted for commercial or subsistence purposes (Pawson *et al.*, 2008). Recreational fishers thus do not sell the fish they catch (Pawson *et al.*, 2008; FAO 2016). Some Mediterranean countries have adopted legislation to regulate and control REC fishing (e.g. fishing license, a minimum size limit) (Gaudin & De Young, 2007). REC fishing, although regulated, can entail serious ecological and economic consequences, and come into conflict with CSS fishing (Venturini *et al.*, 2017). However, various socio-economic factors (e.g. low income and high unemployment rate) can lead to the spread of illegal fishing in some countries (Drammeh, 2000). Moreover, Illegal fishing (IF) concerns all types of fishing vessels, regardless of their size or gear (Gallic & Cox 2006). Worldwide, available fisheries data generally omit the catch from recreational fisheries (Font & Lloret, 2013, Pauly & Zeller 2016), and illegal-unreported fishing activities (Pauly & Zeller 2016). The lack of monitoring and integration of these two fishing statistics has retarded the understanding of the full scale of the coastal fishing sector (Cook & Cowx, 2004; Pauly & Zeller, 2016). Thus, monitoring REC and IF, in competition with CSS, represents a key priority for coastal zones management, particularly in the context of Marine Protected Areas (MPAs). Fishing effort and catch data are crucial for proposing suitable fishing regulations within MPA management plans. MPAs with no-take zones have been widely recognized as a tool that, under certain conditions, can achieve both fisheries management and conservation goals (Guidetti *et al.*, 2014, Batista *et al.*, 2015; Di Franco *et al.*, 2016). Most of the Mediterranean MPAs are coastal and interact with small-scale fisheries. Thus, it is of crucial importance to consider the human dimension (e.g., social, cultural and economic factors) that can seriously affect the implementation and management of MPAs (Charles & Wilson, 2009). In this context of coastal fishing in MPAs, CSS is a very common activity in Tunisia (southern Mediterranean Sea). It plays an important economic role with CSS fishermen operate from 70 coastal ports (of a total of 87). The Tunisian CSS fleet includes 10 227 vessels (88% of the Tunisian fishing fleet). CSS fishing accounts for 25.15 % of total national fisheries production (annual statistics of the Tunisian Ministry of

Agriculture and Fisheries, 2015). On the other hand, REC fishing is an emerging activity along the coasts of Tunisia. REC fishers registered with the Tunisian Federation of Subaquatic Activities (FAST) during the year 2013 were estimated at 3000 (Halouani *et al.*, 2015). No data about the number of non-registered REC fishers is available. Legislation has been adopted in Tunisia to regulate REC activities since 1995. For instance, a REC fishing license is required for spearfishing (using boats or from the shoreline) and for rod fishing and trolling using boats. REC fishing of all groupers species is prohibited. A daily catch of 5 kg is allowed per fisher. In addition, the sale of catches is not allowed. In the present work, CSS fishing, REC fishing and IF were monitored in two future Marine Protected Areas (MPAs) in Tunisia, located in coastal areas where human activities are intensive and ecosystems are under multiple fishing pressures. The aim of this study is to investigate the potential competition between different coastal fishing categories (CSS, REC and IF). To do so, catch data and information on fishers' socio-economic status were collected. Fishing categories were compared in terms of catch composition, mean catch, catch trophic level, vulnerability of caught species, their commercial value in Tunisian local markets and the size-frequency distribution of four fish species of very high commercial value. Temporal variability of the aforementioned metrics for each fishing category was also assessed.

V.3. Methods

V.3.1. Study areas

Two future MPAs, regularly frequented by coastal fishers, were selected as case studies, and are hereafter referred to as 'locations': Tabarka (A) is situated in north-western Tunisia, and the future MPA will cover a surface of 327.855 ha, down to 40 meters depth. The Kuriat islands future MPA (B) is located off the east coast of Tunisia, covering 19 674 ha, down to 40 meters depth (Figure V.1).

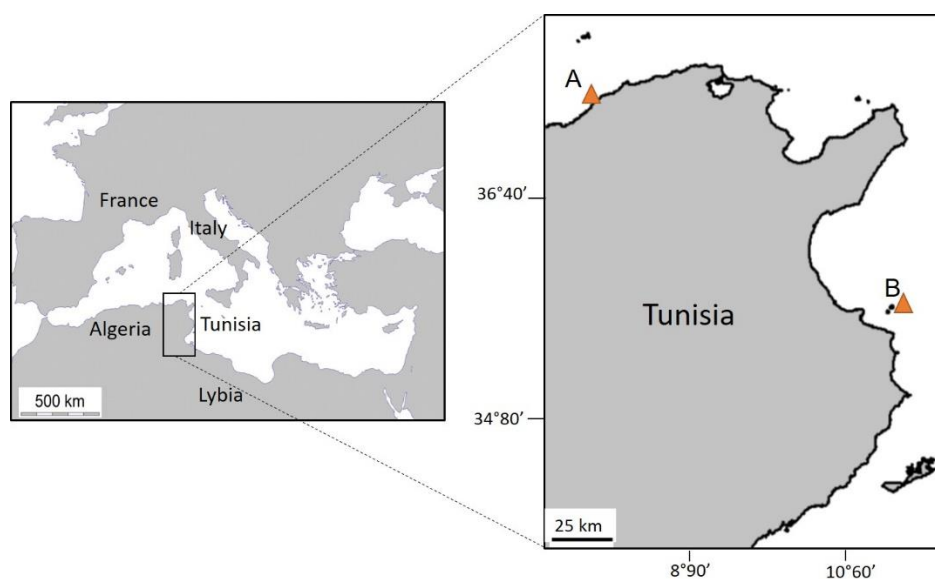


Figure V.1. Location of two future Tunisian MPAs (thereafter called locations); each is indicated by an orange arrow. A= Tabarka, B=Kuriat islands. Sampling at Tabarka (A)

V.3.2. Data collection

For two years (2014 and 2015), field surveys were conducted using questionnaires and catch monitoring, by surveyors in port at Tabarka and offshore at Kuriat islands. The surveys covered four days per month (11 months at Kuriat and 8 at Tabarka). Further details on temporal replication are given in Table V.1. This method was used to facilitate communication with fishers following the approach adopted in other studies (e.g. Johannes, 1993; Huntington, 2000; Close & Hall, 2006; Gerhardinge *et al.*, 2006). In addition, surveyors emphasized that the survey was anonymous and was totally unrelated to law enforcement and to management agencies. During each interview, fishers were questioned to ascertain fishing habits and other socio-economic aspects (age, employment status). Non-professional fishers were also asked whether they sold their catches or not. None of the fishers appeared reluctant to provide this information, likely because the interviewer was a member of the local community at each sampling location. Then, for each fisher interviewed, catch species were identified to the lowest possible taxon (species or genus if species identification was not possible). During surveys, the size of each individual caught was recorded to the nearest 5 cm. Then, individual wet weight estimates were derived using length-weight relationships published in Fishbase (<http://www.fishbase.org/>).

Table V.1. Number of fishers interviewed during the two-year sampling campaign, displayed by year (2014 and 2015), location, periods (month) of sampling and fishing category Table V.1. Number of fishers interviewed during the two-year sampling campaign, displayed by year (2014 and 2015), location, periods (month) of sampling and fishing category. (Total population of CSS fishermen obtained from the Tunisian Ministry of Agriculture, 2014; 2015), JAN: January, DEC: December, JUL: July, KU: Kuriat Islands, TA: Tabarka, nd: no data. Survey was conducted offshore at Kuriat Islands and in port at the two other locations.

Fishing category	periods	Locations	Fishers interviewed		Total population
			2014	2015	2015
Commercial small-scale Fishing (CSS)	JAN-DEC	KU	32	28	nd
	MAY-DEC	TA	60	51	91
Illegal Fishing (IF)	JAN-DEC	KU	16	13	nd
	MAY-DEC	TA	25	18	nd
Recreational fishing (REC)	JAN-DEC	KU	18	16	nd
	MAY-DEC	TA	17	14	nd

Based on socio-economic criteria collected, three fishing categories were distinguished:

- (1) Commercial Small-Scale fishing (CSS): professional fishermen with small boats, no longer than 12 meters, with outings of two days maximum, fishing with trammel nets or longline.
- (2) Illegal Fishing (IF): non-professional fishers who declared selling their catches (banned under Tunisian law), fishing by spear, rod or trolling.
- (3) Recreational (REC): fishers who practice recreational fishing, as defined in Pawson et al. (2008), as a leisure activity, with catches destined for personal consumption, fishing by spear, rod or trolling.

In total, 308 interviews were conducted: 123 at Kuriat islands, and 185 at Tabarka (Table V.1). In all, 19.5% of the interviewees (13% recreational and 6.5% CSS fishers) were not willing to

participate in the survey. Altogether, 213 interviews resulted in exploitable information regarding fishing operations and were retained for analysis.

Information on the total population of CSS fishers was obtained from the Tunisian Ministry of Agriculture for 2014 and 2015. At Tabarka, the number of boats surveyed represented, for 2014 and 2015, 69% and 56%, respectively, of the total CSS fishing boats operating in the area (60 and 51 out of 91 CSS boats in Tabarka port). However, at Kuriat Islands, the population of CSS fishers is unknown. The islands are not inhabited and there is no port. CSS fishers who usually fish there come from 5 nearby towns. It was not possible to estimate the population of non-professional (recreational or illegal fishers) at either of the two locations.

V.3.3. *Data analysis*

For each fishing category, based on catches recorded (all species), five indexes were calculated:

(1) Species richness (**SR**) in the catch as the total number of species caught per fishing category and per location, then the mean per fishing category was calculated.

(2) Mean daily catch per fisher per **day (MC)**: this metric was used because catch per unit of effort is difficult to standardize between the different categories of fishing assessed since each of the fishing methods uses very different fishing gear (Lloret & Font, 2013).

(3) Weighted Mean Trophic Level (**MTL**) index (Pauly *et al.*, 1998): was calculated for each fishing operation as the arithmetical mean of the trophic index of each species, weighted by their catch. The values of species trophic level were obtained from Fish Base (www.fishbase.org) and from Valls *et al.* 2012, where trophic level was available per size class. Trophic levels of cephalopods were obtained from unpublished data (Francour P., unpublished data). MTL has been previously used to assess changes in global fishing landings (e.g. Pauly *et al.*, 1998; 2002, Xu *et al.*, 2009).

(4) Mean weighted Intrinsic Vulnerability Index (**IVI**) (Cheung *et al.*, 2007): was calculated for each fishing operation as the arithmetical mean of the IVI of each species weighted by its catch. Species IVI was obtained from Cheung *et al.*, 2007. IVI in Cheung *et al.* 2007 is calculated using fuzzy logic expert systems and is based on the life history and ecological characteristics of marine fish, such as maximum body length, age at first maturity, the Von-Bertalanffy growth parameter K,

natural mortality rate, maximum age, geographical range, annual fecundity and the strength of aggregation behavior (Cheung *et al.*, 2007). The index values range from 1 to 100. Most vulnerable fish (IVI=100) are the long-lived and slow-growing species with low reproductive potential. It is for this reason that species with higher intrinsic vulnerability have a higher rate of decline (Cheung *et al.*, 2007). Cephalopods were excluded because no IVI has been computed for them. When species information was not available, the genus intrinsic vulnerability was used.

(5) Mean weighted Catch Price (**MCP**): three local markets were surveyed twice in each season in 2014 and 2015. An average price per kg was estimated per season and per year for each species. This price was then converted to US dollars (we used the exchange rate from the Central Bank of Tunisia, available for 2014 and 2015 online: https://www.bct.gov.tn/bct/siteprod/tableau_statistique_a.jsp?params=PL212010&la=AN).

Then, for each fishing operation, mean weighted price of the catch was calculated as the arithmetical mean of the price of each species weighted by its catch.

In addition, mean catch per fishing category was calculated for high and medium economic value species and size frequency per fishing category for very high economic value species (price per kg > 10 USD, see table V.2 in Supplementary Material V.2 for further details).

For data analysis, univariate tests were performed to compare fishing categories, and to assess the seasonality, using the indexes (1 to 5) described above, as variables. Five matrices were used, composed of one index each, and 213 samples from fishing operations data at the two locations. All matrices were analyzed using 4-way permutational analysis of variance (PERMANOVA) (Anderson, 2001): ‘fishing category’ (fixed factor, three levels: Commercial Small Scale (CSS), Illegal Fishing (IF) and Recreational (REC)), ‘location’ (random factor with 2 levels: Kuriat islands and Tabarka), ‘season’ (fixed factor, 4 levels (Winter, Spring, Summer and Autumn)), and ‘year’ (random factor, two levels: 2014 and 2015) Pairwise tests were run whenever appropriate. MonteCarlo permutations were used whenever the number of possible permutations was < 200. The PRIMER 7 and PERMANOVA + package, were used to perform the analyses.

V.4. Results

Between 47.91% (at Kuriat islands) and 71.15% (at Tabarka) of total interviewed non-professional fishers admitted selling their catch, and so were classified as illegal fishers because admitted selling their catch and declared fishing as primary occupation. On average, CSS fishers fished 11 ± 3 days per month, using trammel net or longline, REC fishers fished 4 ± 2 days per month using troll, rod or spear gun, while on average, illegal fishers fished 8 ± 2 days per month using only spear gun.

The general trends of both MC and SR (figure V.2 (a) and (b)) show that IF, CSS and REC fluctuated through years and seasons in both studied locations. Permanova showed that species richness (SR) did not vary consistently between locations, seasons and years (interaction 'lo x se x ye' significant, see table V.3 and table V.4 in Supplementary Material V.2). In addition, Permanova also showed that SR did not significantly vary between fishing categories (factor fishing category and all its interactions non-significant). At Kuriat Islands, (Figure V.2-a) in 2014 SR increased significantly in Summer and then decreased significantly in Autumn for CSS and IF. In 2015, SR varied significantly between Winter and Summer and between Winter and Autumn (Table V.3 and V.4 in Supplementary Material V.2). At Tabarka (figure V.2-b, Table V.3 and V.4 in Supplementary Material V.2), SR varied significantly only in 2014 between Summer and Autumn.

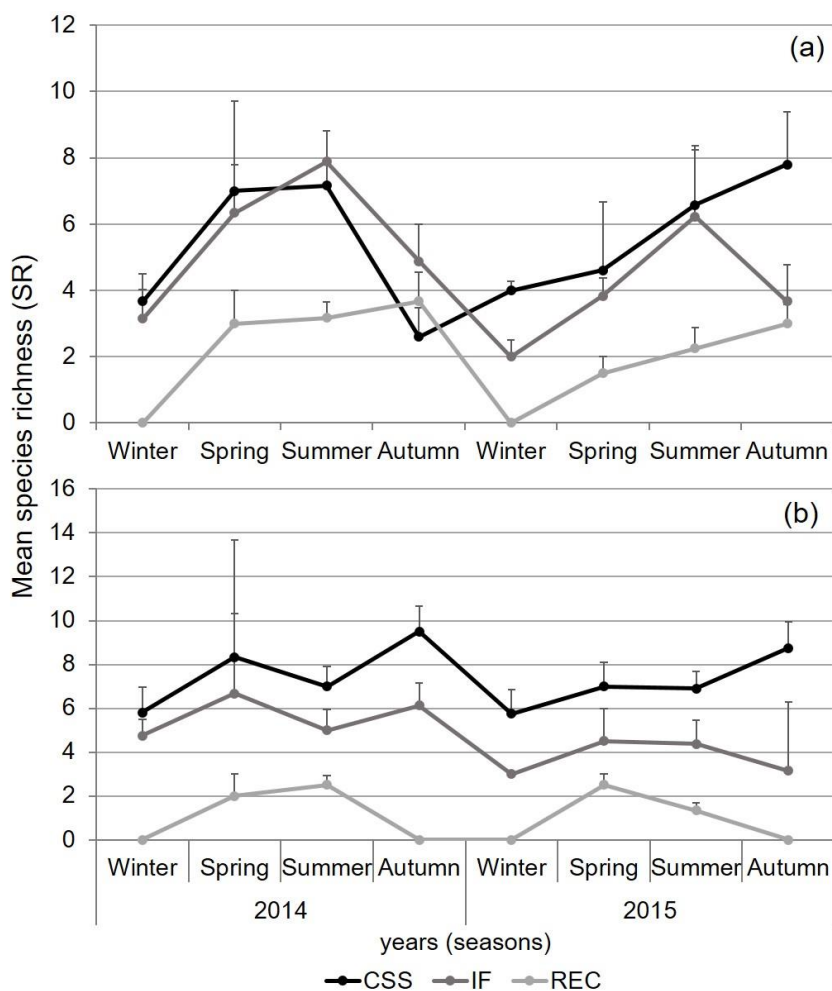


Figure V.2. Species richness ($RS \pm$ standard error), per year and per seasons at Kuriat Islands (a) and at Tabarka (b), CSS: Commercial Small-Scale fishing, IF: Illegal Fishing, REC: Recreational fishing.

MC per fishing category changed significantly at the spatial and temporal scales considered (i.e. between locations, months and years) (interaction ‘fishing category x location x month x year’ significant, p -value <0.05 , see table V.5 and table V.6 in Supplementary Material V.2), and at the temporal scale of season alone (interaction ‘fishing category x season’ significant). At Kuriat Islands (figure V.3-a), during the year 2014, MC-IF was significantly lower than MC-CSS and significantly higher than MC-REC in all seasons. In Winter 2015, MC-IF was higher than MC-CSS, a trend which increased until Summer to decrease slightly again in Autumn. The differences between the two variables were not significant for all seasons. MC-CSS was significantly higher than MC-REC only in Autumn 2014 and 2015. At Tabarka (figure V.3-b). MC-CSS was significantly higher than

MC-IF in all seasons in 2014, and higher than MC-REC only in Summer 2014. During 2015, significant differences were found between MC-CSS and MC-IF in Summer and Autumn, between MC-CSS and MC-REC in Spring and Summer, while no significant differences were found between MC-REC and MC-IF.

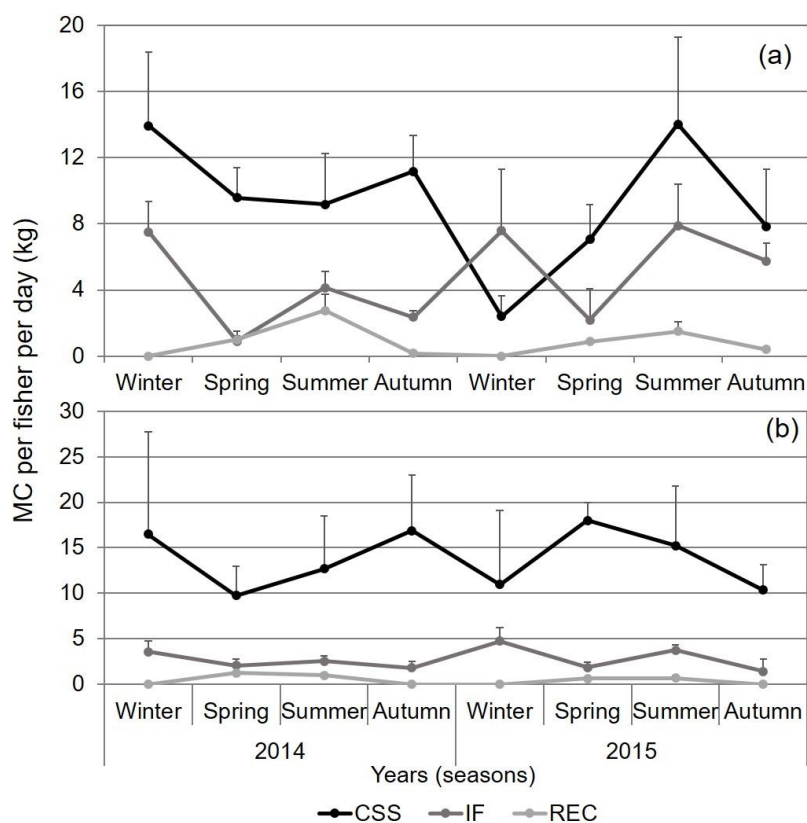


Figure V.3. Mean Catch per fisher per day (kg) ($MC \pm se$), per year and per season at Kuriat Islands (a) and at Tabarka (b), CSS: Commercial Small-Scale fishing, IF: Illegal Fishing, REC: Recreational fishing.

Species of commercial interest (Figure V.4, see Supplementary Material V.2) are presented by their catch percentage in each fishing category. High trophic level predators such as *Mycteroperca rubra*, *Epinephelus marginatus*, and *Epinephelus costae* were caught mainly by IF (between 70% and 100% of species catch, respectively for *E. marginatus* and *M. rubra*). CSS and IF were in competition for *Sciaena umbra*, *Octopus vulgaris*, *Sparus aurata*, *Dentex dentex* and *Dicentrarchus labrax*, while REC competed with CSS for *Serranus cabrilla*, *Coryphaena hippurus* and *Lichia amia* (figure V.4).

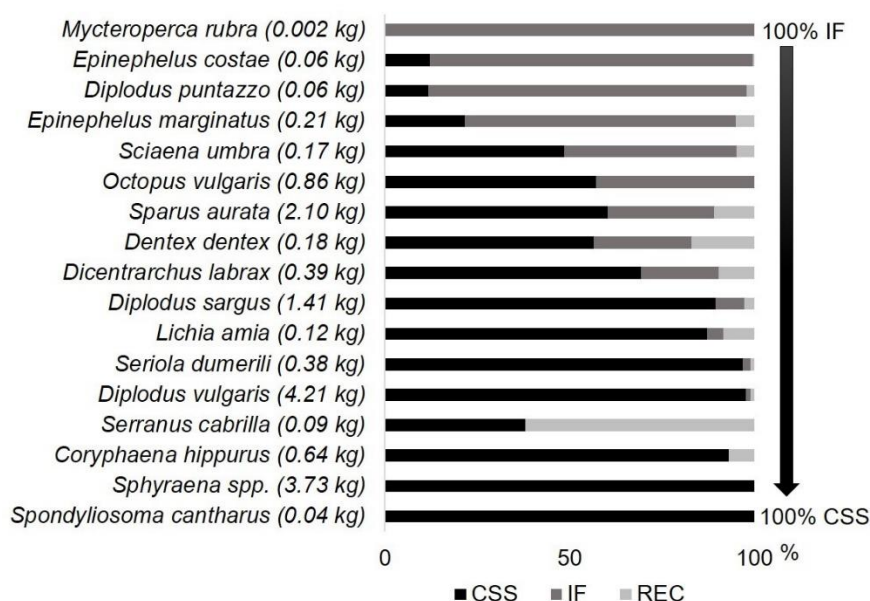


Figure V.4. Species mean daily catch (kg) (all fishing categories) and percentage per fishing category (CSS: Commercial Small-Scale fishing, IF: Illegal Fishing, REC: Recreational).

Species are listed from the top to the bottom in decreasing percentage of catch per IF (and increasing per CSS).

Catch MTL was comprised between 3.51 ± 0.04 for CSS fishing and 3.59 ± 0.07 for REC fishing. IF catch MTL was 3.57 ± 0.06 (Figure V.5-a; Table V.7 in Supplementary Material V.2). Permanova showed that MTL varied consistently between fishing categories, locations, seasons and years. (no significant difference for all factors and interactions). Mean weighted IVI ranged from 46.62 ± 0.74 for CSS to 47.40 ± 1.32 for IF (Figure 5-b; Table V.8 in Supplementary Material V.2). IVI did not display any significant differences in spatial and temporal patterns (no significant difference between fishing categories, locations, months and years). All interactions were not significant either for this index. MCP ranged from $5.12 \text{ USD} \pm 0.19$ per CSS (per fisherman per day) to $8.30 \text{ USD} \pm 0.53$ per IF (Figure V.5-c). MCP was significantly different between fishing categories (factor 'fishing categories' significant (Pseudo-F= 2.24, p-value<0.05). Pairwise test showed that IF and REC catch prices are comparable and significantly higher than those of CSS (IF, CSS: p-value<0.001 and REC, CSS: p-value<0.05). No spatial and temporal variation was attributed to this index (no significant difference between locations, months and years, nor for all interactions (Table V.9 in Supplementary Material V.2).

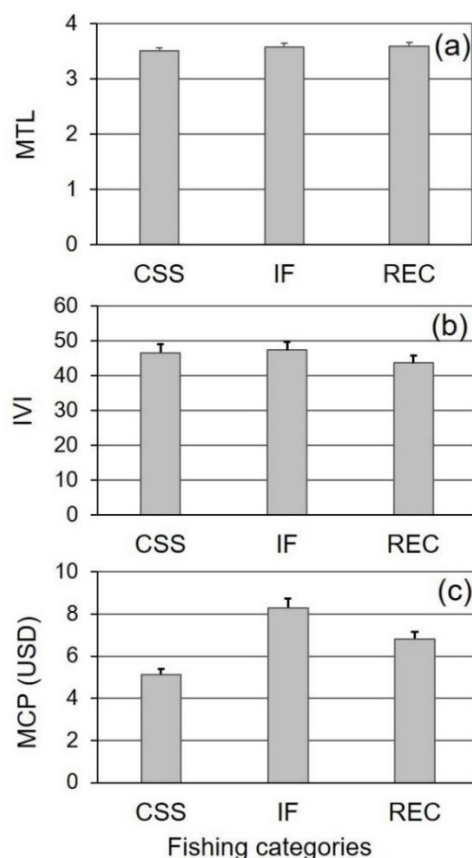


Figure V.5. (a) Mean Trophic Level ($MTL \pm$ standard error), (b) Mean Intrinsic Vulnerability Index ($IVI \pm$ standard error), per fishing category and (c) Mean weighted local price of catches ($MCP \pm$ standard error), displayed by fishing category, (CSS: Commercial Small-Scale fishing, IF: Illegal Fishing, REC: Recreational fishing)

Size frequency of four species of very high economic value (see Supplementary Material V.2) showed that all three fishing categories caught individuals at sizes under maturity length (Figure V.6). CSS fishing caught only small size classes for all species. In IF catches, only 8% of individuals had sizes larger than maturity length. Concerning REC, 13% of caught individuals of *Sciaena umbra* and *Epinephelus marginatus* had sizes larger than maturity length.

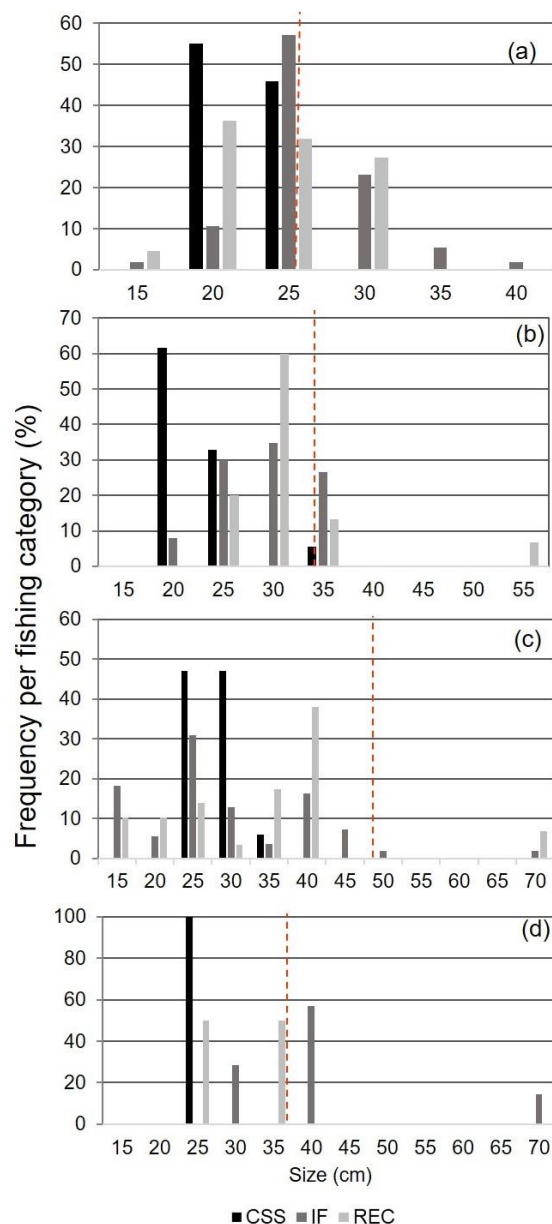


Figure V.6. *Sciaena umbra* (a), *Dentex dentex* (b), *Epinephelus marginatus* (c) and *Epinephelus costae* (d) size-frequencies distributions by fishing category (CSS: Commercial Small-Scale fishing, IF: Illegal Fishing, REC: Recreational). For each species, the dotted vertical red lines identify size at first maturity (according to Tsikliras and Stergiou, 2014).

V.5. Discussion

Data on coastal fishing in the Mediterranean Sea are generally very scarce, and when available are sporadic (Prato *et al.*, 2016). Few studies have considered both commercial small-scale and recreational fishing (see Lloret & Font, 2013; Albouy *et al.*, 2010; Prato *et al.*, 2016). Previous

studies in the Mediterranean Sea categorized coastal fishing as: (1) Commercial Small-Scale (CSS) fishing, and (2) Recreational fishing (REC), including spearfishing, rod fishing (boat and shore fishing), and trolling (e.g. Edelist *et al.*, 2013; Rocklin *et al.*, 2011; Marengo *et al.*, 2015; Lloret & Font, 2013). Another approach was used in this work to describe coastal fishing, considering, in addition to CSS and REC fishing, the illegal component of coastal fishing (CSS and REC fishing legal framework established since 1994 by 'arrêté ministériel' (Ministerial Decree) of 20th September 1994). Illegal fishers use the same techniques as recreational fishers, but sell their catch on the black market, instead of using it for personal or family consumption. The percentage of illegal fishers out of the total of non-professional fishers (at the two locations, between 47.91% and 71.15%) was lower than that reported in Tunca *et al.* (2016) at two Turkish MPAs, where 96% of recreational fishers also declared selling their catch. Although non-professional fishers in our study showed no reluctance in declaring to the interviewer that they were selling the catch, the possibility that a fraction of illegal fishers did not want to admit selling the catch cannot be excluded. This being so, estimation of the incidence of illegal fishing could be considered as conservative, and the true picture is that this activity could be even more widespread. Illegal Fishing (IF) is widespread in many coastal zones, among them certain European MPAs (Prato *et al.*, 2016). A recent work on Australia's Great Barrier Reef Marine Park highlighted that illegal fishing is also a serious issue in this iconic MPA, where high levels of poaching have been recorded (Bergseth *et al.*, 2017).

By selling their catch on the black market, Tunisian illegal fishers generate revenues critical for their subsistence, but they are also creating illegal and unfair competition with CSS fishers. In future Tunisian MPAs, as in other Mediterranean MPAs, IF should be vigorously combated and discouraged, not only because of its extent but also because illegal fishers are rapidly improving their fishing techniques to catch more valuable fish at relatively low cost. For instance, some of them are using new artificial baits, such as jigs, that seem to increase the catchability of vulnerable species such as the common dentex *Dentex dentex* (Lloret *et al.*, 2016, Venturini *et al.*, 2017).

In comparison to CSS mean catches per day, IF and REC catches represented 40% (5.22 ± 0.95 kg per fisher per day) and 20% (2.62 ± 0.74 kg per fisher per day), respectively. Other studies in Tunisia reported that mean catch per day per recreational fisher (spear and rod fishing) could be as high as 5.5 kg (Besta, 2016; Khalfallah, 2015). The former estimation does not account for the component of illegal fishing. Temporal and spatial variations were also highlighted in mean

catch and in species richness. REC fishing highest MC were recorded in Summer. This is consistent with findings from other Mediterranean regions (e.g. Lloret & Font, 2013; Lloret *et al.*, 2008; Marengo *et al.*, 2015). CSS fishing and IF occurred in all the seasons. IF highest catch occurred in winter at both locations while CSS highest catch was registered in different seasons at both locations. This temporal pattern is also similar to other studies in the Mediterranean Sea, where CSS prefer cold season to get the highest catches (Lloret & Font, 2013, Forcada *et al.*, 2010). The novelty in the present study is that it is highlighted that the IF come to compete with CSS fishing in the same seasons, and its MC can be higher locally than MC-CSS. In particular, at Kuriat Islands, during winter, IF compete with CSS fishing for *Octopus vulgaris*. Temporal patterns between fishing categories should be carefully considered in establishing fishing regulations and management practices for both studied locations.

Mean catch of species of medium and high economic value showed a high overlap for many species. CSS and IF compete for high trophic level predators e.g. *Epinephelus marginatus*, *Epinephelus costae*, *Sciaena umbra*, *Dentex dentex*, and for *Dicentrarchus labrax*, *Sparus aurata* and the cephalopod *Octopus vulgaris*. On the other hand, CSS and REC compete for *Seriola dumerili*, *Lichia amia*, *Serranus cabrilla* and *Coryphaena hippurus*. The calculated MTL of the catch is considered as high for all fishing categories (higher than overall MTL for coastal fisheries in the Mediterranean region, reported in Pauly *et al.*, 1998 (~3 in the year 2000)). Fishing high trophic level predators can have a serious ecological and economic impact by altering the functioning of the ecosystems and reducing the sustainability of the fishing activities (Pauly & Watson 2005). Moreover, IF and REC caught most economically valuable fish and cephalopods. The effective control of illegal fishing and fishing regulations can play an important role in restoring local populations and finally ecosystems. Regulating the non-professional fishing effort (REC and IF) might reduce the impact on high TL predators and increase the availability for CSS fishing of higher TL catches (Rocklin *et al.*, 2011; Prato *et al.*, 2016), which are generally more valuable on the market, thus providing economic benefits for the CSS fishing industry.

The three studied fishing categories target intrinsically vulnerable species. Reported catch IVI ranged from moderate to high value (IVI between 40 and 60, according to Cheung *et al.*, 2009). They are also comparable to those reported at Medes Islands; i.e: 41.22 for CSS and 54.15 for spear fishing (Lloret & Font, 2013). Moreover, CSS-IVI (the lowest among the other fishing

categories) was higher than Mediterranean coastal exploited fish species IVI (~46 in 2000) according to Cheung et al., 2007. If these trends -continue, it is likely that the more vulnerable species will suffer considerable risk of population depletion, extirpation or extinction (Cheung *et al.*, 2009). Among the different species caught by IF and CSS, three species are included in the categories 'endangered', 'vulnerable' or 'near threatened' of the IUCN Red List (*Epinephelus marginatus*, *Dentex dentex* and *Sciaena umbra*). Other species in the catch had high IVI, such as: *Mycteroperca rubra*, *Epinephelus costae*, *Sphyraena* spp. *Coryphaena coryphaena* and *Lichia amia*. Moreover, at least 50 % of grouper catches and at least 86% of brown meagre catches were under size at maturity.

The future Tunisian MPAs (studied in our work) will include certain management measures aimed at regulating fisheries (e.g. no-take areas, gear exclusion, catch and/or effort control), based on proposed management plans. The creation of an MPA is frequently accompanied by opposition from fishers (Christie, 2004; Rice *et al.*, 2012). In addition to restrictive measures for recreational fishing in future MPAs, the illegal component should also be taken into account as it is a widespread practice at the studied locations (e.g. organizing patrols at locations where poaching may be more likely (Bergseth *et al.*, 2017)). Moreover, Illegal fishers could oppose the enforcement of MPAs (recreational fishing restrictions) by poaching (Bergseth *et al.*, 2017). Optimizing enforcement and using communication strategies focused on fishers (Gutiérrez *et al.*, 2011; Schemmel *et al.*, 2016) are two key aspects of ensuring compliance in MPA management. Cooperation in monitoring and management processes is a critical component for the success of an MPA (Guidetti *et al.*, 2008; Claudet & Guidetti, 2010; Arceo *et al.*, 2013; Di Franco *et al.*, 2016;). For example, the implementation of communication and information campaigns, in which fishers participate actively, can be effective to reduce poaching (Bergseth *et al.*, 2017), and can play a role in achieving higher rates of MPA acceptance and success (Lloret *et al.*, 2012; Batista *et al.*, 2015). Thus, further investigations focused on measures used to estimate compliance, and the factors that regulate human behavior in conservation, are needed (Bergseth *et al.* 2017).

In conclusion, the importance of considering commercial small-scale, recreational and illegal fishing, in parallel, is highlighted. This enhances the understanding of the ecological and socio-economic dimensions of coastal fisheries. These findings emphasize the extent of illegal fishing and its unfair competition with the other, legal fishing activities. To provide coastal fishery

and MPA managers with a solid basis on which to develop sound management measures will result in real progress in the sustainable use of marine resources in coastal zones and in MPAs.

Supplementary materials 1:

Table V.2. Fish species' commercial interest in Tunisia: we define medium commercial value species: price per kg <5 USD, (5 USD is the daily minimum guaranteed wage in Tunisia, available online: <http://www.ins.tn/fr/themes/salaires>), high commercial value specie: price per kg >5 USD and < 10 USD (twice the daily remuneration), and very high commercial species (price per kg > 10 USD). Information about seasonality is also given. When no month is mentioned, it means that the species is fished all the year.

Fish species	Commercial interest	Price per kg (USD)	Seasonal species
<i>Mycteroperca rubra</i>	Very high	14.28	-
<i>Epinephelus costae</i>	Very high	14.28	-
<i>Epinephelus marginatus</i>	Very high	14.28	-
<i>Dentex dentex</i>	Very high	14.03	-
<i>Sciaena umbra</i>	Very high	12.75	-
<i>Dicentrarchus labrax</i>	High	9.18	-
<i>Seriola dumerili</i>	High	9.18	-
<i>Sparus aurata</i>	High	8.16	-
<i>Sphyreana</i> spp.	High	8.41	-
<i>Lichia amia</i>	high	7.39	-
<i>Coryphaena hippurus</i>	High	7.05	July-September
<i>Octopus vulgaris</i>	High	6.13	October-March
<i>Diplodus puntazzo</i>	Medium	2.55	-
<i>Diplodus sargus</i>	Medium	2.55	-
<i>Diplodus vulgaris</i>	Medium	2.55	-

<i>Serranus cabrilla</i>	Medium	1.78	-
<i>Spondilosoma cantharus</i>	Medium	1.78	-

Supplementary materials 2: Permanova and Pairwise tests tables

Table V.3. Permanova used on resemblance matrix of species richness per fishing category, fishing category (fi), location (lo), year (ye) and season (se), *p-value < 0.05

Source	df	SS	MS	Pseudo-F
Fi	2	10264	5131.9	1.49
Lo	1	588.93	588.93	1.83
Se	3	2979.3	993.1	1.07
Ye	1	1140	1140	3.9
FixLo	2	958.43	479.22	0.7
FixSe	5	1879	375.81	0.99
FixYe	2	6754.8	3377.4	4.94
LoxSe	3	6774.8	2258.3	1.33
LoxYe	1	249.47	249.47	0.37
SexYe	3	1252.8	417.61	0.29
FixLoxSe	4	925.01	231.25	0.38
FixLoxYe	2	1368.3	684.16	1.03
FixSexYe	5	3586.1	717.22	1.16
LoxSexYe	3	5496.9	1832.3	2.77*
FixLoxSexYe	4	1808.3	602.76	0.91
Res	172	1.12E+05	660.84	
Total	213	1.80E+05		

Table V.4. Pairwise test with Monte-Carlo permutations on resemblance matrix of species richness per fishing category, i.e. on the significant interaction ‘location x season x year’ (‘Lo x Se x Ye’) and among the factor ‘season’.

Locations	Kuriat islands		Tabarka	
	2014	2015	2014	2015
Winter, Spring	1.85	1.83	0.65	0.95
Winter, Summer	4.33***	2.75**	0.58	0.5
Winter, Autumn	0.95	1.97*	1.29	0.6
Spring, Summer	1.08	1.17	0.61	1.22
Spring, Autumn	1.78	0.78	1.25	0.76
Summer, Autumn	1.93*	0.65	2.21*	0.2

Table V.5. Permanova used on resemblance matrix of mean daily catch per fisher data (MC), fishing category (Fi), location (Lo), year (Ye) and season (Se), *p-value < 0.05, **p-value<0.01

Source	df	SS	MS	Pseudo-F
Fi	2	31203	15601	0.4
Lo	1	2672.3	2672.3	2.11
Se	3	5472.3	1824.1	0.49
Ye	1	937.01	937.01	0.7
FixLo	2	86418	43209	14.29*
FixSe	5	16332	3266.4	2.26*
FixYe	2	13226	6613.1	2.31
LoxSe	3	9898.7	3299.6	2.15
LoxYe	1	1263.1	1263.1	0.86
SexYe	3	10444	3481.3	2.29

FixLoxSe	4	5711.1	1427.8	0.37
FixLoxYe	2	6044.1	3022.1	2.05
FixSexYe	5	8298.6	1659.7	0.47
LoxSexYe	3	4591.5	1530.5	1.04
FixLoxSexYe	4	15228	3807	2.59**
Res	172	2.51E+05	1468.3	
Total	213	5.31E+05		

Table V.6. Pairwise test with Monte-Carlo permutations for the combined factor “fishing category (fi) x location (lo)”, on mean daily catch per fisher. Tests were performed on the significant interaction “fishing category x location” (fi x lo) and among the factor “fishing category” (fi) (CSS: Commercial Small-Scale fishing, IF: Illegal Fishing, REC: Recreational fishing); * p-value<0.05; **p-value < 0.01; ***p-value<0.001

Locations	Years	Season	Fishing categories		
			CSS vs IF	CSS vs REC	REC vs IF
Kuriat Islands	2014	Winter	2.46*		
		Spring	3.40**	1.26	4.89**
		Summer	2.95**	1.52	2.58***
		Autumn	3.11**	2.88*	2.15*
	2015	Winter	0.67		
		Spring	1.27	1.19	2.61*
		Summer	1.53	3.45**	4.87***
		Autumn	1.11	4.09**	1.63
Tabarka	2014	Winter	8.45*		
		Spring	3.01**	1.1	1.28

	Summer	3.93**	2.68**	1.94
	Autumn	3.45***		
	Winter	2.22		
2015	Spring	2.34	6.63*	0.54
	Summer	3.41***	3.23***	1.17
	Autumn	3.38***		

Table V.7. Permanova used on resemblance matrix of weighted Mean Trophic Level (MTL) data, fishing category (Fi), location (Lo), year (Ye) and Season (se)

Source	df	SS	MS	Pseudo-F
Fi	2	281.47	140.74	0.65
Lo	1	12.35	12.35	0.58
Se	3	142.9	47.63	0.74
Ye	1	73.66	73.66	3.01
FixLo	2	79.24	39.62	3.16
FixSe	5	392.95	78.58	1.05
FixYe	2	390.69	195.35	13.35
LoxSe	3	129.45	43.14	0.79
LoxYe	1	21.12	21.12	0.65
SexYe	3	256.68	85.56	1.77
FixLoxSe	4	73.82	18.45	0.28
FixLoxYe	2	25.02	12.51	0.39
FixSexYe	5	563.6	112.72	1.82
LoxSexYe	3	162.07	54.02	1.68
FixLoxSexYe	4	262.66	65.66	2.04

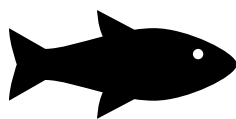
Res	172	5518.5	32.08
Total	213	7560.5	

Table V.8. Permanova used on resemblance matrix of weighted intrinsic vulnerability index (IVI) data, fishing category (Fi), location (Lo), year (Ye) and Season (se)

Source	df	SS	MS	Pseudo-F
Fi	2	284.45	142.22	1.58
Lo	1	56.125	56.12	0.37
Se	3	449.82	149.94	1.63
Ye	1	212.78	212.78	1.59
FixLo	2	232.6	116.3	1.36
FixSe	5	127.8	25.55	0.88
FixYe	2	66.78	33.39	0.38
LoxSe	3	316.17	105.39	1.8
LoxYe	1	148.53	148.53	1.46
SexYe	3	116.36	38.78	0.56
FixLoxSe	4	306.96	76.74	1.2
FixLoxYe	2	170.04	85.01	0.84
FixSexYe	5	125.03	25	0.36
LoxSexYe	3	175.01	58.33	0.57
FixLoxSexYe	4	255.72	63.93	0.63
Res	172	17384	101.07	
Total	213	21158		

Table V.9. Permanova used on resemblance matrix of mean catch price (MCP) data, fishing category (Fi), location (Lo), year (Ye) and Season (se), *p-value < 0.05

Source	df	SS	MS	Pseudo-F
Fi	2	9421.4	4710.7	2.24*
Lo	1	612.66	612.66	0.2
Se	3	1446.5	482.17	0.75
Ye	1	3131.3	3131.3	1.39
FixLo	2	4531.2	2265.6	1.93
FixSe	5	2411.4	482.28	0.57
FixYe	2	1076.2	538.11	0.48
LoxSe	3	1227.8	409.27	1.72
LoxYe	1	2966.6	2966.6	5.62
SexYe	3	1707.6	569.21	1.82
FixLoxSe	4	2227.8	556.95	1.66
FixLoxYe	2	2340.2	1170.1	2.21
FixSexYe	5	4254.3	850.85	2.38
LoxSexYe	3	711.72	237.24	0.44
FixLoxSexYe	4	1336.2	334.04	0.63
Res	172	90743	527.57	
Total	213	1.27E+05		



Monitoring fishing pressure in the Tunisian future MPAs was conducted using questionnaires and monitoring of landed catch. This was useful to describe coastal fishing. Even if catch estimation is not that precise, data collected were informative. Results showed that coastal fishing (CSS and recreational) in Tunisia is confronted to a high proportion of illegal fishing. To understand ecological and socio-economic attributes of coastal fisheries, it was necessary to carry out a big sampling effort and to involve some artisanal and recreational fishers that were willing to help. Illegal fishers were those who use the same techniques as recreational fishers (mostly gunspears) and who declared selling the catch (which is prohibited by the Tunisian Law). Our findings emphasize the extent of illegal fishing since at least 47.9% of total nonprofessional fishers declared selling the catch. This fishing is highly and unfairly competing with the other legal fishing activities. Having the assistance of local fishers (some of course) showed their awareness and implication in monitoring procedure which could represent an initiation to the volunteer based programs in fisheries monitoring in these locations. Our findings have also implications for developing conservation and management plans in coastal zones and in MPAs, that could enhance and sustain commercial small-scale fishing.

*Chapter VI: Assessing coastal
fishing (2): Toward the
assessment of Commercial Small
Scale (CSS) fishing in Tunisian
future MPAs*

VI.1. Abstract

Commercial Small Scale (CSS) catch monitoring was performed on board in three Tunisian locations, using trammel nets, during Summer 2016. The object of this work is to assess accurately CSS fishing catch inside and outside future MPAs, and to provide “before impact” data that can be used in the future, i.e. when MPAs are created and enforced. According to Simper analysis, most determinant fish in biomass were Sparidae, Sciaenidae, Dasyatidae, Congridae and Scorpaenidae. Overall, biomass was not significantly different between zones (future protected and unprotected), but varied significantly between locations. Abundance differed significantly between zones only in one location. Biomass caught per 100-meter net was low in all locations, in comparison with other Mediterranean fished areas. Further sampling series using the same technique need to be performed outside the future protected locations to get data series to compare once protection is effective. This method can be very useful also to enhance communication with fishermen.

VI.2. Introduction

CSS fisheries (also called also Commercial Small Scale (CSS) fisheries) are part of the history and culture of Tunisia, where CSS vessels account for about 80% of the professional fishing fleets (Tunisian Ministry of Agriculture, 2015). CSS fisheries are important from a socio-cultural and economic point of view (CAR/ASP & PNUE-PAM, 2014; Halouani *et al.*, 2015). Recently, the decrease of catch and income per vessel, led to dramatic reductions of artisanal fleets in many Mediterranean countries (up to 50%; Gómez *et al.*, 2006).

Marine Protected Areas (MPAs), were found to have the potential to enhance local fisheries (Harmelin-Vivien *et al.*, 2008; Guidetti *et al.*, 2014; Di Franco *et al.*, 2016). Fishermen, can get benefits from fishing near marine reserves, by exploiting spillover of target species from MPAs (Goñi *et al.*, 2008; Forcada *et al.*, 2009; Di Franco *et al.*, 2016). There is an urgent need of field studies in order to assess whether MPAs can actually work in enhancing local fisheries (Guidetti & Sala, 2010). In terms of whole recovery of fish stocks, no-take reserves have been found generally more effective than buffer MPAs (or partial reserves, see Di Franco *et al.*, 2009). MPAs with buffer zones, from this perspective, can be important scenarios for experimenting with novel approaches to CSS fishing management in order to try to fit in this traditional extractive activity with conservation needs (Guidetti & Claudet, 2010, Seytre *et al.*, 2013). To start monitoring CSS fishing in future MPAs in Tunisia, we used the experimental fishing to collect exhaustive data and to

enhance communications with fishermen. Being on the boat during fishing operation allows to the scientific a rare proximity of fishermen, fostering communication with them and living in their daily fishing operations. Within this chapter, the objective is to assess catch and to compare it inside and outside the future protected areas.

VI.3. methods

VI.3.1. Sampling sites and locations

Experimental fishing using trammel nets was performed at three locations: Tabarka, Cap Negro-Cap Serrat and Kuriat Islands. Each location encompassed 4 sites that will be protected (i.e. that will be included within an MPA), and 2 adjacent sites (controls) that will remain open to fishing. Sampling was performed between 25 and 35 m depth, at 3 of the same diving sites in each location inside yellow circles (Figure VI.1), during Summer 2016. Sampling was replicated three times at each site. The nets were immersed for approximately 12 h.

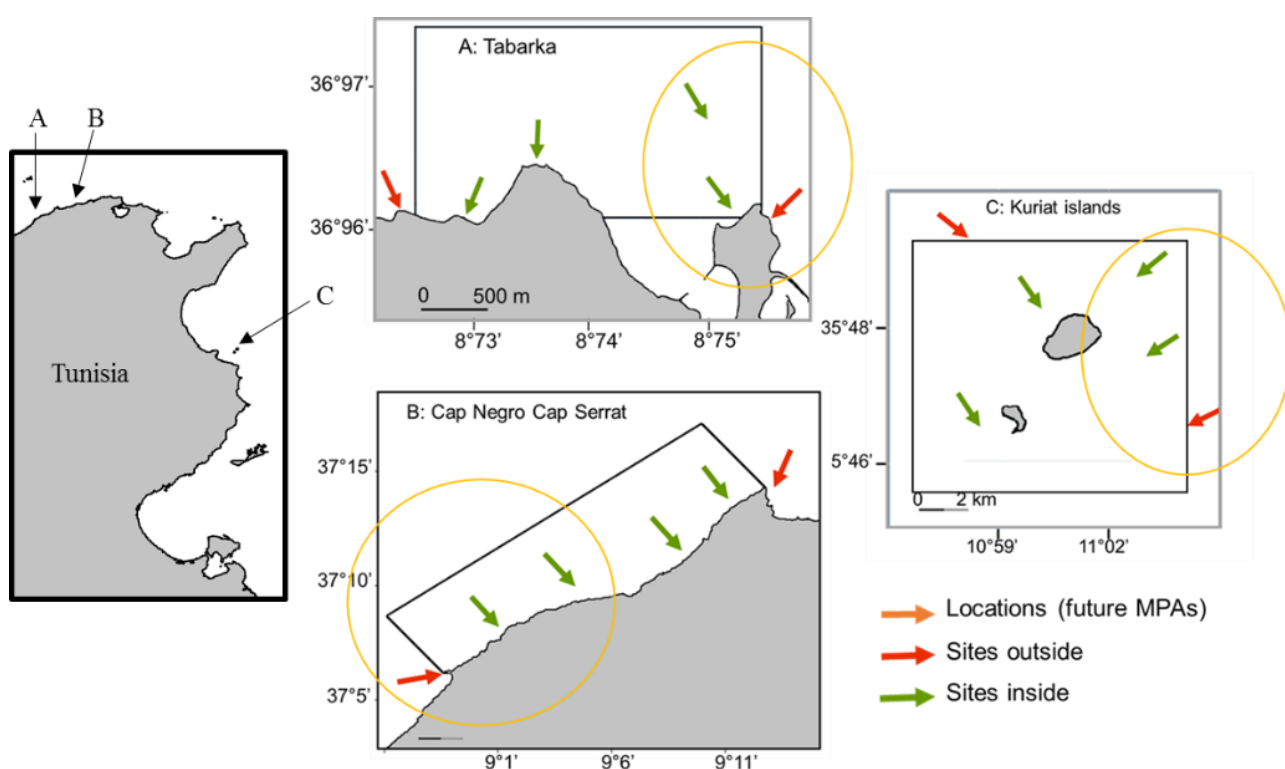


Figure VI.1: Locations with sites of experimental fishing in yellow circles in comparison to all sampling sites using UVC.

VI.3.2. Data collection

Experimental fishing was performed by fishermen in each location using their own gear: trammel net composed of 10 to 15 pieces of 50 meters length each. Mesh size varied between 15 mm and 30 mm. For each site. Caught species were then identified to species level, counted, measured and weighed to the nearest 10 gr.



Figure VI.2. Experimental fishing method used on board of artisanal fishing boats (Ben Lamine, 2016)

VI.3.3. Data analysis

To understand typology of catch, we proceeded to a “similarity percentage breakdown” (SIMPER) analysis (Clarke *et al.*, 2006) to rank species contributions to the dissimilarity between samples per zone for each location.

Then, using data collected per species, four metrics were calculated: Biomass per 100 meters of net as the mean caught biomass (in kg) per future protection level in each location (therefore calculated per species).

Species richness (SR) is computed as the mean number of species caught per fishing operation, a mean was then calculated for each zone (future protected and zones that will remain fished). Large fish proportion is calculated as the percentage (over the total catch) of fish which total length is upper than 2/3 common length reported in the literature.

Finally, carnivores proportion is computed as the percentage (over the total catch) of carnivores and large predator species (as defined in Guidetti & Sala, 2007).

Statistical tests were performed using multivariate analysis and univariate analysis. Permutational Analysis of Variance (Permanova) was applied firstly on two resemblance matrices composed of biomass and abundance per species and n=26 samples, each. Then, using univariate analysis, Permanova was applied on transformed data of 4 matrices. Each one was composed separately by one of the four variables (total biomass, species richness, total abundance, proportion of large sized fish and proportion of carnivores) and n= 26 samples. For all analyses, Factor “zone” (Zo) (2 levels, Future Protected (FP) and Un-Protected (UP)) was considered as fixed. Factor “location” (3 levels: Kuriat, Cap Negro Sidi Mechreg, Tabarka) was considered as random. We used MonteCarlo permutations whenever the number of possible permutations was < 200. The PRIMER 7 and PERMANOVA + package, were used to perform the analyses. Pairwise tests were used whenever appropriate.

VI.4. Results

Overall, thirty-five fish species from 16 families and 2 species of commercially valuable invertebrates were captured by the trammel nets (*Sepia officinalis* and *Palinurus elephas*).

VI.4.1. Catch per species

Simper analysis applied on abundance and biomass fish species matrices showed that the species that contributed the most in the catch were:

- ❖ For abundance: Kuriat islands : Outside: *Diplodus sargus* (35.12%), *Diplodus annularis* (33.28%) and *Mullus surmeletus* (22.28%), Inside: *Belone belone* (31.72%), *Mullus surmeletus* (24.45%), *Sarpa salpa* (13.10%) and *Diplodus vulgaris* (12.00%)

Cap Negro Cap Serrat: Outside: *Mullus surmeletus* (87.34%), Inside: *Sphyraena spp.* (47.68%), *Diplodus vulgaris* (21.46%), *Spondiliosoma cantharus* (20.53%)

Tabarka: Outside: *Scorpaena scrofa* (37.01%) and *Diplodus vulgaris* (35.63%), Inside: *Diplodus vulgaris* (61.55%) and *Serranus cabrilla* (16.01%)

❖ For biomass: **Kuriat islands** Outside: *Diplodus sargus* (32.07%), *Mullus surmeletus* (23.73%) and *Sarpa salpa* (22.50%), Inside: *Diplodus annularis* (25.15%), *Mullus surmeletus* (22.61%), *Sarpa salpa* (14.60%) and *Diplodus vulgaris* (10.14%)

Cap Negro Cap Serrat Outside: *Mullus surmeletus* (86.43%), Inside: *Sphyraena spp.* (33.88%), *Sciaena umbra* (22.48%) and *Diplodus vulgaris* (19.70%)

Tabarka Outside: *Scorpaena scrofa* (62.33%) and *Diplodus vulgaris* (26.65%), Inside: *Diplodus vulgaris* (67.98%) and *Serranus cabrilla* (11.20%)

As shown in figure VI-3 diagrams, in Kuriat islands, most determinant fish in biomass were Sparidae. While in Cap Negro Cap Serrat, the most fished species were *Sciaena umbra*, *Dasyatis pastinaca* and *Conger conger*. Finally, in Tabarka, caught biomass was mostly dominated by *Scorpaena scrofa* catch.

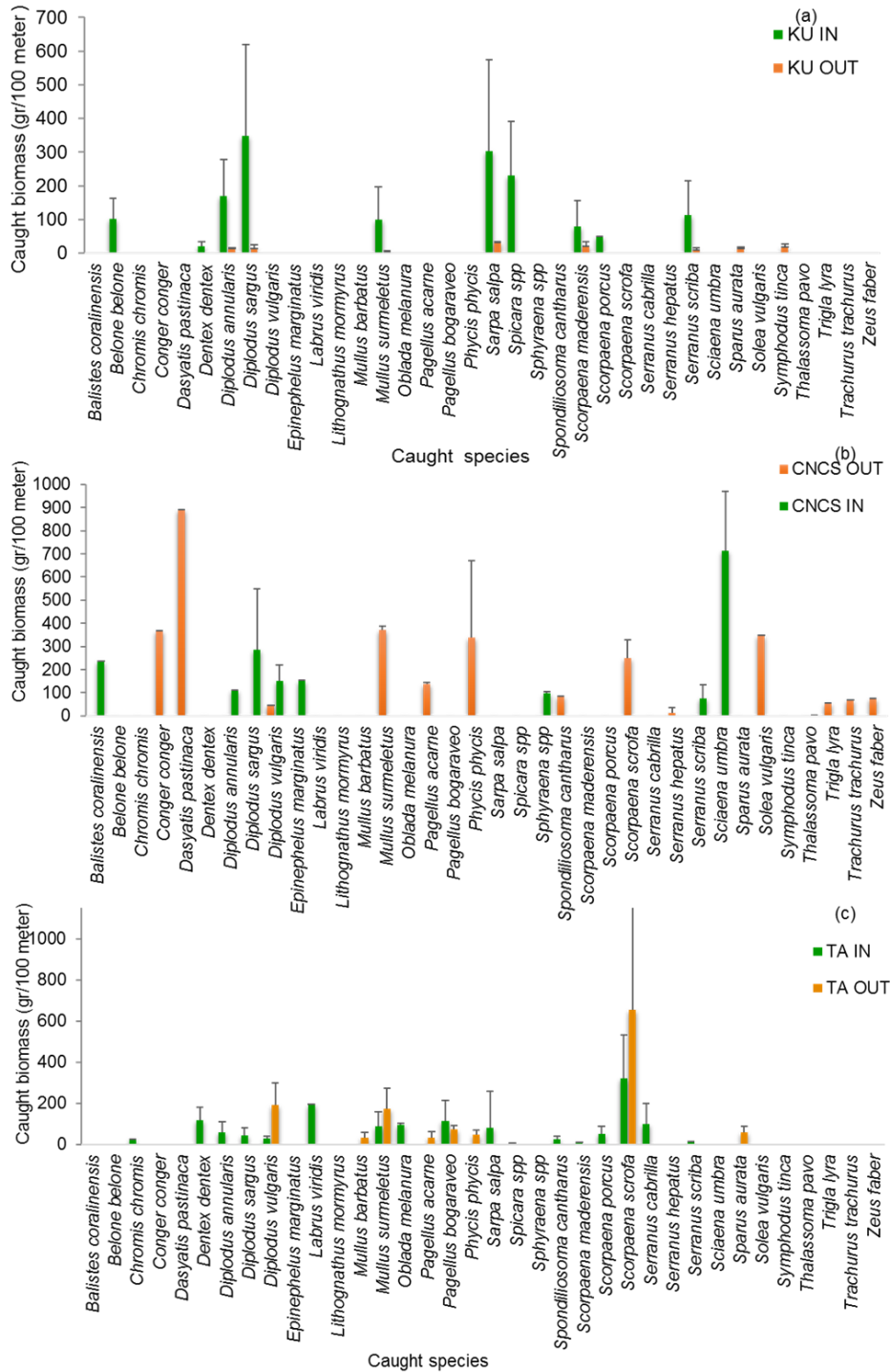


Figure VI.3: Caught biomass per species in Kuriat (KU) (a), Cap Negro Cap Serrat (CNCS) (b) and Tabarka (TA) (c) inside (green) and outside (orange) with error bars

VI.4.2. Multivariate analysis

Overall, multivariate analysis applied on species biomass showed a coherent pattern between zones but not between locations (factor Lo significant). Species abundance was also not coherent between locations and differed significantly between zones (interaction “Zo x Lo” significant). Pairwise test applied on the significant interaction showed only significant difference in abundance between inside and outside Cap Negro Cap Serrat location ($p < 0.05$).

Table VI.1. Multivariate analysis (Permanova) for species biomass and abundance (*: $p < 0.05$; **: $p < 0.01$)

Metric		Biomass		Abundance	
Source	df	MS	Pseudo-F	MS	Pseudo-F
Zo	1	7806.3	1.91	8183.9	1.44
Lo	2	6489.3	1.70*	6303	1.68**
ZoxLo	2	4067.4	1.06	5665.3	1.51*
Res	21	3805.8		3730.2	
Total	26				

VI.4.3. Univariate analysis

The highest mean abundance was recorded in catch outside Kuriat islands (92.33 ± 22.24 / per 100-meter nets) (significantly higher outside than inside). In all other sites, mean abundance did not exceed 51.62 ± 18.43 ind. / 100-meter nets. However, highest mean biomass was recorded in sites outside Cap Negro Cap Serrat (41.28 ± 17.49 gr/100-meter nets). Otherwise, mean biomass ranged between 9.79 ± 0.45 and 28.06 ± 15.52 gr/100-meter nets. There was significant difference in abundance and biomass between zones (inside and outside) which was not coherent within locations (interaction “Zo x Lo” significant). Species richness did not differ from a zone to another in all locations (figure VI.4 and table VI.5). Concerning large size fish and carnivore proportion did not exceed 50% of the catch, with similar patterns between zones and locations (figure VI.5 and Table VI.5).

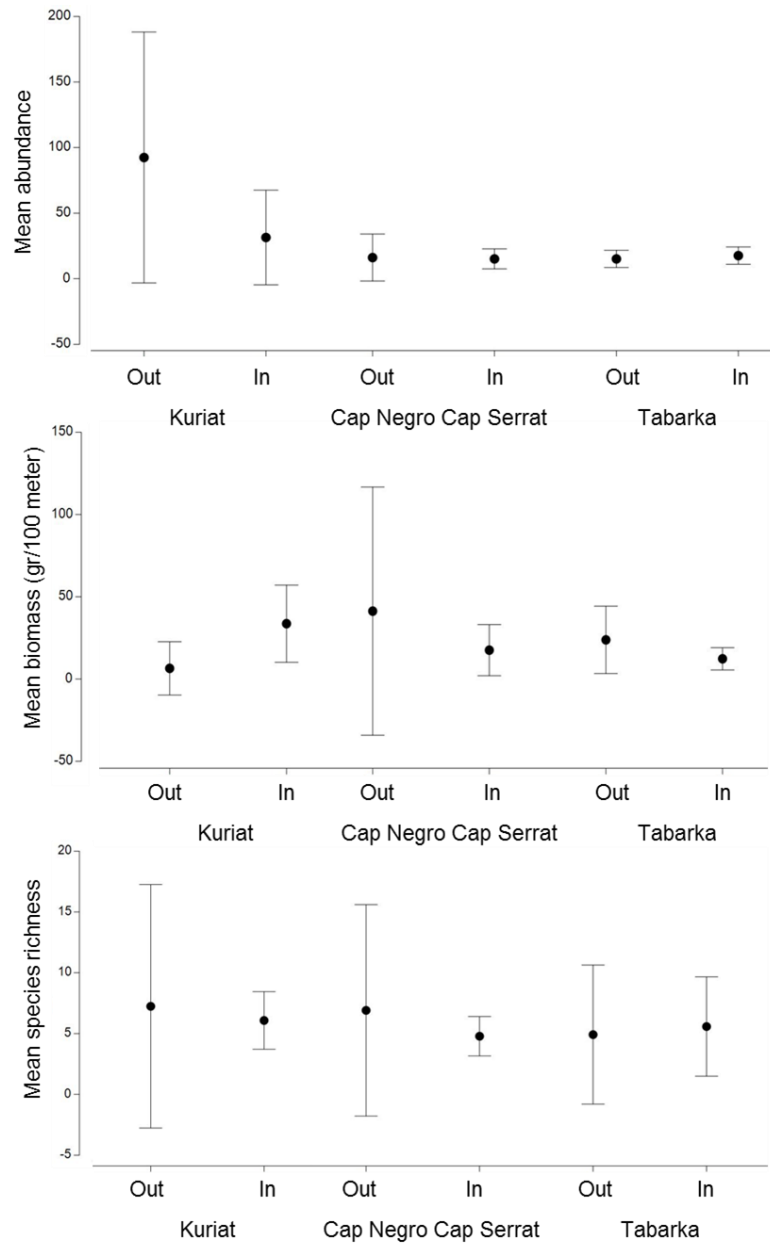


Figure VI.4. Mean abundance, mean biomass and mean species richness per 100-meter nets in catch outside and outside each location

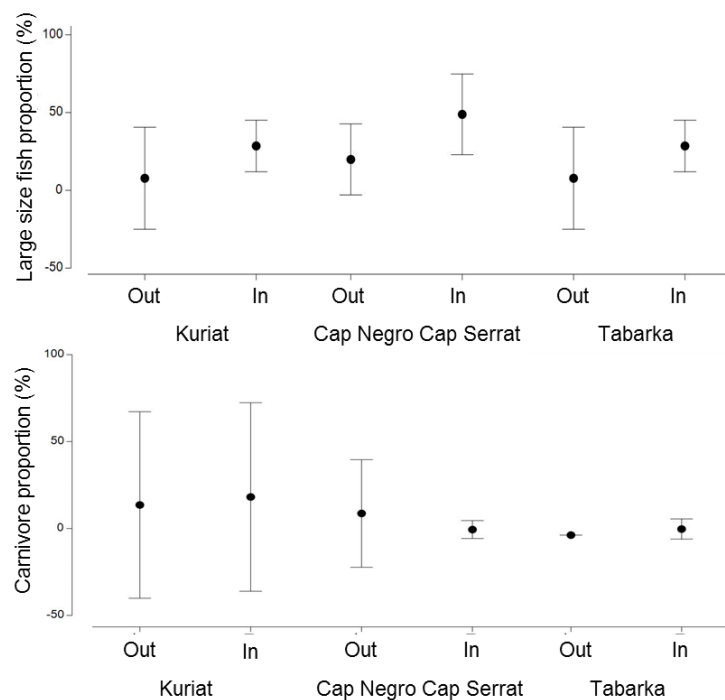


Figure VI.5. Large sized fish proportion and carnivore proportion in catch outside and inside each location

Total abundance presented different patterns between zones only in Kuriat islands (pairwise test, $p < 0.05$). Large sized fish proportion differed significantly between zones also but only in Cap Negro Cap Serrat location. Total biomass was not coherent between zones at the spatial scale of locations (interaction “Zo x Lo” significant). Species richness and proportion of carnivores did not differ between zones. It did not vary between locations, either.

Table VI.2. Univariate analysis (Permanova) for biomass, abundance, species richness, large sized fish proportion and carnivores proportion (*: $p < 0.05$; **: $p < 0.01$)

Univariate	df	biomass		abundance		species richness		large proportion		carnivores proportion	
		MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
Zo	1	42.05	0.03	2360.2	0.92	4.52	1.14	13.06	0.00	1	0.00
Lo	2	280.12	1.04	5633.6	12.5**	4.04	0.45	2461.5	6.58**	642.16	1.39
ZoxLo	2	1377.1	5.12*	2548.2	5.65*	3.94	0.44	4015.4	10.73**	117.94	0.25
Res	21	268.78		450.45		8.81		373.92		460.33	
Total	26										

VI.5. Discussion

In many Mediterranean MPAs regulated fishing activities are allowed within buffer zones often surrounding no-take areas. Then, if MPAs' borders encompass pre-existing communities of CSS fishermen, a complete ban of fishing is not conceivable. Specific regulations can be adopted to reduce the overall fishing impact, possibly enhancing local artisanal fisheries in the long-term (Boudouresque *et al.*, 2004; Stelzenmuller *et al.*, 2007; Cadiou *et al.*, 2009). Therefore, CSS fisheries management in MPAs is strictly dependent on local socio-cultural conditions (e.g., which regulate the relationships among fishermen and their attitudes towards the conservation issues (Bergseth *et al.*, 2017).

The use of the same fishing gear as the fishermen each time allowed also to get a realistic idea about catch and its diversity. In comparison with transects method, the same commercial species were caught by experimental fishing, except some cryptic species as *Scorpaena scrofa* that were not censused during UVC in the same locations. *Scorpaena scrofa* is known as a nocturnal predator (Harmelin-Vivien *et al.*, 1989). Then, *Trigla lyra* is deep water species (100 - 700 m, Fishbase; Louisy, 2015). It was accidentally caught in shallowest waters.

Biomass caught per 100-meter net was low in all locations (9.79 ± 0.45 to 41.28 ± 17.49 gr per 100 meters net), in comparison with other Mediterranean fished areas (e.g. fished zones in Torre Guaceto, 1kg (Guidetti *et al.*, 2010), 2 kg in fished areas adjacent to Tabarca marine reserve (Forcada *et al.*, 2009) per 100-meter nets). Large Proportion (LP) and Carnivores Proportion (CP) were also at low percentages of the total catch, in all locations, inside as outside.

Further sampling series using the same techniques need to be performed outside the future protected locations to get data series to compare once protection is effective. It is expected that caught biomass, and large proportion will increase at the borders of the future MPAs, as it is the case in other Mediterranean MPAs (Seytre *et al.*, 2013, Guidetti *et al.*, 2010).

*Chapter VII: Assessing coastal
fishing (3): the use of photo-
surveillance method*

VII.1. Introduction

In the Mediterranean, marine reserves may allow fish predators of sea urchins to recover and thus whole communities to be restored from coralline barrrens to macroalgae (Guidetti *et al.*, 2008). The effectiveness of MPAs and achievement of their conservation and fisheries enhancement goals have been subject to numerous studies and reflexions. Their performance and effectiveness were related to several key factors. MPAs success is highly dependant from: (1) degree of fishing permitted or protection level (2) level of enforcement, (3) age, (4) size and (5) isolation (Edgar *et al.*, 2014, Halpern, 2014). More specifically, positive effects of MPAs were directly linked to higher enforcement levels (Edgar *et al.*, 2014, Rossiter & Levine, 2013, Guidetti *et al.*, 2008; McClanahan *et al.*, 2006). In well enforced MPAs, positive responses were observed for high trophic level predators (e.g. dusky groupers) and sea urchin predators. Those with low or null enforcement did not differ from fished areas (Guidetti *et al.*, 2008; McClanahan *et al.*, 2006; Guidetti *et al.*, 2014).

To assure a well level of enforcement, the strategy needed at the national level is the one where major efforts and funds are invested in enforcing the regulations in MPAs and equipping them with surveillance personnel devoted to this task. Funds and personnel can be very limited in some contexts and even when they are available, they are not enough in large MPAs which have to be controlled and monitored to assure their performance and efficiency. Covering all zones using patrolling is not that easy task. An alternative solution can be the use of photography and video techniques. They are cost-effective, by removing the need for observers in the field and by allowing simultaneous collection of a much wider amount of information with a very good image quality in a permanent record that can be analysed later (Cappo *et al.*, 2003).

Photography and video techniques were used for observing coastal marine biodiversity. Technologies are used since 1961 (by Lafond *et al.*, 1961 In Mallet & Pelletier, 2014). They are increasingly in use in marine ecology studies and most of them were used in USA and Australia (Mallet & Pelletier, 2014). Many studies on fish assemblage used underwater video to calculate fish assemblage metrics density, species richness (Watson *et al.*, 2005) and fish size using calibrations devices (Cappo *et al.*, 2003; 2004). They were used as complements to observational sampling technique to UVC is video and a number of studies have compared fish assemblages recorded using each technique (e.g. Francour *et al.*, 1999; Willis & Babcock 2000; Tessier *et al.*, 2013). Video transects were used for large scale monitoring along a network of MPAs in Hawaiï (Ortiz & Tissot,

2008). Otherwise, underwater photography was used to measure human impact on benthic community in Mediterranean Sea (recreational scuba dive) (Parravicini *et al.*, 2008). These video / photography methods can help to fill some of the monitoring gaps. Photography method was used to monitor frequentation by users and fishers (all categories included) in locations with accessibility limited (e.g. some islands). “Photo-surveillance” method, where a hidden camera takes photos continuously to record human activities in its field of view. It was applied in the national park of Zembra and Zembretta (gulf of Tunis) since April 2016. Using photo-surveillance, it is expected to record frequentation data (in number of boats, which kind of boats (fishing, recreational), what they are using to fish, at what time, ... etc).

In the National marine park of Zembra and Zembretta (future MPA), it is in the Gulf of Tunis and it is known to host a lot of professional and recreational fishing activities (practiced illegally). Even though it is protected by Tunisian law (since 1977), there is still no enforcement. Many challenges are facing enforcement and some of them are directly related to the difficulties of living conditions and the lack of financial resources. So, the idea behind this proposed method is to be partially informed of what is happening in some parts of the island. Then, it is more useful to get these information in a useful format for monitoring. Outputs of this method are photos, which constitute considerable information source of a good quality. For example, they are treatable using Geographical Information Systems (GIS) for spatial planning or can be just used to extract information.

VII.2. Method

VII.2.1. study MPA

The Zembra and Zembretta future MPA is situated on the North East of Tunisia (Gulf of Tunis). It is an archipelago composed of

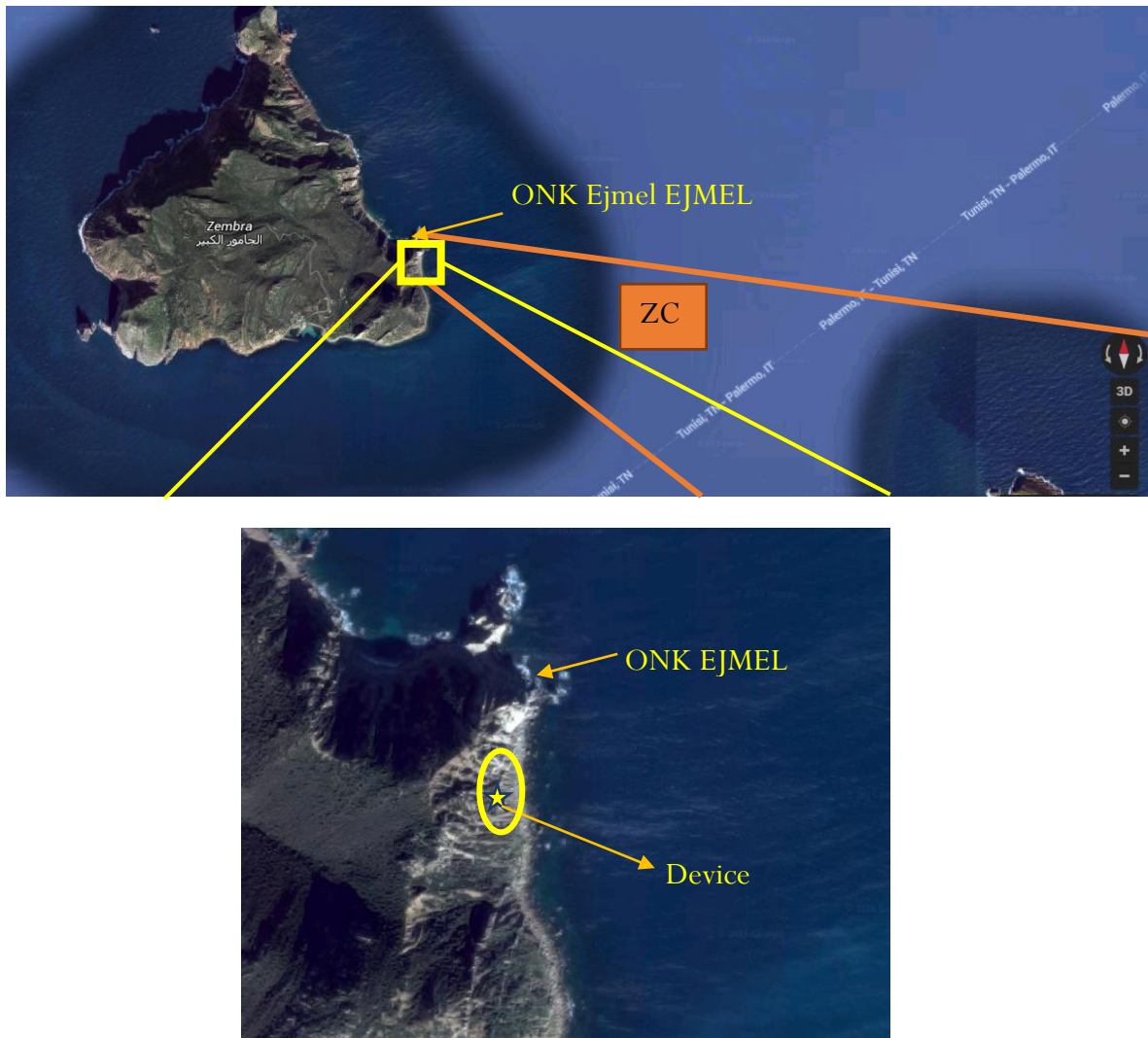


Figure VII.1: google earth images of the site in Zembra and Zembretta

VII.2.2. *Prospection and choice of the site*

The choice was made in concertation with APAL managers using some criteria:

- ❖ Somewhere accessible but not that accessible (to impede users from displacing it or even steel it)
- ❖ Somewhere it is possible to have the largest field of view to cover especially one zone suffering to illegal trawling.
- ❖ Somewhere it can be well hidden and integrated into landscape and nature

At the end, the choice landed on the south east of Zembra (called later ZC1, figure VII-1)

VII.2.3. Device description

The installed device to take continuously photos of the site ZC1 comprises a camera and an external battery put together in a closed wooden box. but more precisely:

- A camera Nikon D7200. with two memory cards (64Go et 32 Go). With its integrated time laps programming function. it was easy to program it to take 2 photos. each 20 min. during day and night.
- An external battery was locally (in Tunisia) designed to cover the camera needs in power so it can continue taking photos for 19 to 22 days.
- The two previously explained components were put in wooden box with its front in glass. using a plastic film and silicon. it was made waterproof. Also. little bags containing rice and small pieces of polystyrene were put into the box to absorb humidity.

The camera has the following characteristics:

- Resolution: 24.7 Mpx (6.5 Mpx)
- Focal: f/3.5. which allowed l'îlot Zembretta
- Actual zoom: 18
- Opening angle: 54°

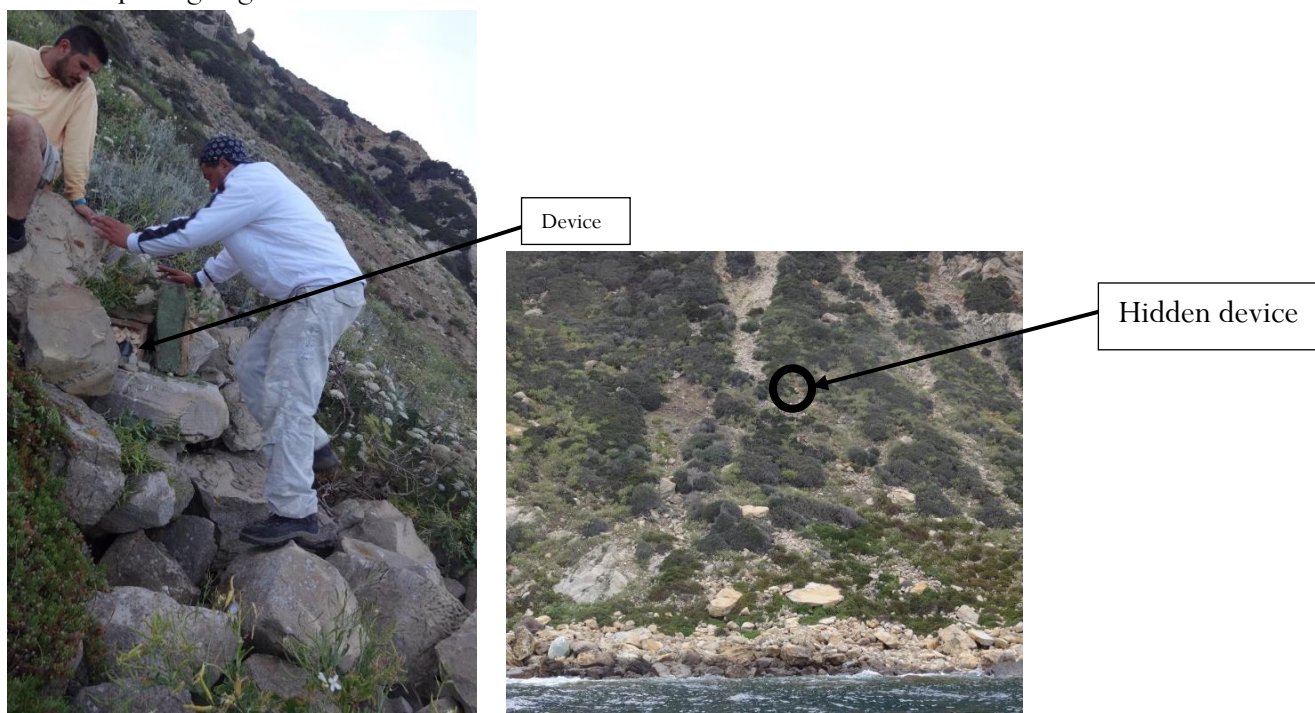


Figure VII.2: hidden device



Figure VII.3. Hidden device and the external battery (on the left)

VII.3. The usefulness of the method?

In situations where the resources for proper enforcement are lacking, alternative management regimes that are better able to meet a range of community goals may achieve greater acceptance, compliance, and subsequent conservation success than systems designed primarily for national interests of tourism and biodiversity conservation.

It is becoming increasingly recognized that a large proportion of marine reserves around the world receive ineffective enforcement. At the reserves where enforcement was high, protection caused significant increases in density of nine fish taxa (all effect sizes for such taxa were >0 and CI did not overlap zero), in most cases represented by large piscivorous fishes and predators of sea urchins there is a suggestive evidence of the role that enforcement exerts in enhancing average fish biomass values relative to local conditions that may change from place to place.

Well-enforced reserves not only can meet ecological and socio-economical objectives, they can also help promote creation of new reserves (Agardy *et al.*, 2003; Friedlander *et al.*, 2003). A better understanding of how compliance and enforcement can affect ecological outcomes can help resource managers and policy-makers design better MPAs in response to the specific management problems needed to be solved or purposes to be served and make well-informed decisions regarding the MPAs and reserves already established. As well, articulating clear objectives for

MPAs can help convert the vehement public opposition usually encountered at the time of MPA establishment (especially by skeptical users like fishermen) into broader acceptance and better chances of success for MPAs (Guidetti *et al.*, 2008).

VII.4. Continuity of this monitoring?

Camera took photos continuously. with some difficulties at the beginning. We must say that checking the camera. get the battery and refill it was widely restricted by the difficulty of access to the site (for landing) and by the absence of electricity in the island. We collected photos showing some boats. However, our collected data are missing regularity to allow us to get pertinent results and conclusions.

This method, as it is, has a potential to provide crucial data for managers when they are not on the field. However, this method is exposed to many risks as bad weather, humidity and stealing. Moreover, the presence of rats in the islands retarded the use of the device for few months.

For the continuity needs of this work, more tests should take place to provide more evidence on the use of the device. The photos treatment is still on process since the data were not regular.

In the future, if the device prove its feasibility, the external battery could even be replaced by a solar generator to be independent from electricity and be more “green” monitoring method.

Funding: this part of the work received funds from the project of fisheries (“Agence de Protection et d’Aménagement du Littoral”)

Chapter VIII: General Discussion

Initial questions

In marine environment, and particularly in MPAs, scientific monitoring is a key to reliable information. Empirical data collected in the field, using adequate methods and experimental designs, are the first reliable source of information to calculate metrics and indices, which represents a crucial step for coastal areas management and decision making. In coastal protected areas, scientific monitoring need to be well-adapted to conservation and management objectives (Albright *et al.*, 2016). Tunisian future MPAs are coastal areas that handle multiple human pressure but that support high biodiversity levels (CAR/ASP & PNUE-PAM, 2014; Zarrouk, 2017).

The legal framework is still incomplete for creating MPAs in Tunisia. The law of 2009 stipulates conditions and requirements to enact MPA creation. The “National Council for Marine and Coastal Protected Areas” was created by the Ministeriel Decree on 28th of April 2017 (JORT 34 of 28th April 2017, according to the Ministerial Decision of 19th of May 2014), about its creation, composition and mission. This means that the decree of MPA designation will be promulgated soon. Surveys performed in this work, for three years, were performed before the legal creation of MPAs.

As in many Mediterranean countries, Tunisian MPAs are being created not only to protect biodiversity, but also to enhance important socio-economic activities (CAR/ASP & PNUE-PAM, 2014; 2015; Zarrouk, 2017). Thereafter, scientific monitoring in MPAs should concern biological and ecological resources on one hand, and socio-economic activities that comes with probable impact (e.g. tourism, recreational diving, professional and recreational fishing), on the other hand.

In many Mediterranean MPAs, reserve effect was assessed using fish assemblage monitoring inside and outside the protected zones (Côté *et al.*, 2001; García-Charton *et al.*, 2004; Claudet *et al.*, 2006; Guidetti & Sala, 2007; Lester *et al.*, 2008; Aburto-Oropeza *et al.*, 2015; Hackradt *et al.*, 2014; Guidetti *et al.*, 2014). Ideally, to assess the reserve effect, it is preferable to apply an ideal experimental design as described in Guidetti *et al.*, 2002, collecting data before and after MPAs creation, outside and inside the protected area, by different protection levels (inside: no-take/ no fishing, and outside: non-protected area i.e. fished area). It is preferable to do the censuses in same season, at the same sites with similar habitat and depth characteristics, to allow reliable statistical

comparisons, avoiding seasonality and habitat effects that can mask resere effect (Garcia-Charton *et al.*, 2000).

The purpose of our work was to select, propose, adapt and test fishing and fish assemblage monitoring methods and indicators for four Tunisian future MPAs, in order to propose a monitoring strategy for fish and fishing monitoring strategy for Tunisian MPAs. Selection of methods and indicators from literature was made according to their feasibility, cost-effectiveness and adequation with the monitoring objectives. Five methods were applied: two methods for fish assemblage monitoring underwater (UVC) and three methods for monitoring fishing activities. UVC methods included one standard method (transects with variable width (TVW)), which was used to collect exhaustive data, counting all fish encountered with precision from 1 cm to 5 cm size class (Prato *et al.*, 2017), and one easy-to-use method (fish assemblage sampling technique (FAST)), presence/absence method using a pre-established list) used with volunteer divers after a scientific training. Fishing monitoring methods tested were the questionnaires and landed catch monitoring, experimental fishing and photography for surveillance. Enough spatial and temporal replicates were sufficiently applied to assure reliability in results and statistical comparisons. So, according to the sub-objectives of our work, several hypothezises have been tested:

S/objective 1: to start a before Impact experimental design for three future MPAs using UVC standard method

Hypothesis 1. Is there is a significant difference between inside (future protected zone) and outside (unprotected zone) in fish assemblage metrics (density, biomass and size distribution)?

S/objective 2: Facing the lack of data in coastal areas and the lack in scientific divers, to propose, adapt and to test an easy-to-use method in collaboration with volunteer divers.

Hypothesis 2. Are the standard UVC method comparable to easy-to-use UVC method (FAST)?

Hypothesis 3. Are the Scientifically Trained Volunteers (STV) results significantly different from scientific diver (SD) ones?

S/objective 3: facing coastal fishing pressure: understanding both ecological and socio-economic attributes of coastal fishing in Tunisia

Hypothesis 4. Using questionnaires and catch landing: Is there a significant difference between coastal fishing categories (commercial small scale, recreational and illegal) using Mean catch, Mean Trophic Level (MTL), Intrinsic Vulnerability Index (IVI), and Mean Catch Price (MCP) indexes?

S/objective 4: To assess with accuracy CSS fishing using experimental fishing method

Hypothesis 5. Using experimental fishing method: Is there a significant difference between inside (future protected zone) and outside (unprotected zone) in CSS fishing metrics (biomass, species richness, Large sized proportion (LP) and Carnivores Proportion (CP))?

S/objective 4: to test the photo-surveillance method

Main results

“Before Impact” experimental design to assess effectiveness of MPAs using standard UVC

The standard method used, the transects with variable width (TVW), allows an accurate census of all fish species. Counting 3 groups of fish in different lengths and widths transects, taking into account their behavior and maximum sizes, increases the efficiency and accuracy of the counts. Using this method, even cryptic species that are generally not counted using a single width transect, are considered (Prato *et al.*, 2017) because the diver is more focused on counting other moving fish in the water column. Using this method, a very good knowledge is required in the identification of the fish and a good experience in size estimation. Compared to single-width transects, TVW method seems to be more effective in counting predators of high trophic or large sizes (eg *Epinephelus marginatus*, *Sciaena umbra*, *Sphyraena viridensis*, *Dentex dentex* and *Mycteroperca rubra*) in AMPs of Cabo de Palos, Scandola and Tavolara (Prato *et al.*, 2017).

In our work, using TVW, an experimental design "Before Impact", formally replicated in time and space, has been proposed for three future AMPs in order to test their effectiveness once they will be created and officially protected. The composition of the taxa of the assemblages recorded showed that fish belonging to the Sparidae, Labridae and Serranidae families were the most represented in terms of the number of species (e.g. Seytre & Francour, 2014, García-Charton & Pérez-Ruzafa, 2001). The distribution of fish stocks in future MPAs and sites (unprotected, protected in the future) in terms of density and biomass was quite variable over time and space.

Observed patterns can be attributed to factors independent of protection, such as habitat type distributions, complexity seascape (see Garcia-Charton *et al.*, 2000) that were not considered in this study. In the future, this result must be taken into account in all follow-ups. This result stresses once again the usefulness of adopting appropriate sampling models, in particular the "Before Impact" experimental design, BACI ("Before After Control Impact"), to test hypotheses correctly related to the effectiveness of MPAs (Guidetti, 2002, Pelletier *et al.*, 2008, Bonaldo *et al.*, 2017).

This study could trigger further research in other countries south of the Mediterranean and in the eastern Mediterranean. This will allow a more comprehensive evaluation of the effects of the MPAs that will be implemented in the region given the large imbalance in studies between these two regions and the northwest of the Mediterranean (PISCO & UNS, 2016, Giakoumi *et al.*, 2017).

Citizen science for fish monitoring in Tunisia: challenges and perspectives

Standard transects methods with variable width are crucial to collect exhaustive data. However, for the Tunisian context (understudied areas), it is essential to intensify the sampling effort of fish assemblages. However, the traditional monitoring programs, applied so far, are restricted by the limited funds and available scientific divers, which entailed many gaps through years. In this context, citizen science is pursued as a cost-effective solution. Recreational divers involved in fish monitoring in three locations did not use TVW but rather easy-to-use and low training needs method, as FAST (Fish Assemblage Sampling Technique), a method relying only on species presence-absence from a pre-established list. Standard methods require an extensive and time-consuming training in species identification and underwater size estimation (Edgar *et al.*, 2014, Aburto-Oropeza *et al.*, 2015).

UVC along transects have been carried out by recreational divers in many MPAs throughout the world (Edgar *et al.*, 2014), but regular fish monitoring in understudied areas is also restricted by the limited funds. Volunteer divers received scientific training on target fish identification (target by fishing, which are usually easy to identify underwater). Before using FAST, we tested its consistency with TVW. Using the same sampling scheme (zones: inside and outside each location), and comparisons between locations data, TVW and FAST showed the same patterns between

locations and zones for all metrics and indices during all time sampling (2014, 2015 and 2016), except the large sized fish metric, where all interactions between factors were significant with TVW, while only one interaction was significant using FAST. This difference can be explained by the the difference in underwater size estimation using each method, i.e. with FAST, size classes estimations (small, medium and large) are used underwater while for TVW size estimations, more accurate size estimation is performed underwater (from 1 to 5 cm precision).

Yet, we consider that both methods are coherent in describing patterns between locations and between zones, which support the proposition of FAST method for fish monitoring as a complement for TVW. Few calibration dives, applying FAST by STV and SD were necessary after the theoretical training. Results showed no significant differences between STV results and SD ones, except, relative species richness index in Cap Negro-Cap Serrat and large proportion index in 2014 and 2015. Size estimation of fish underwater is an important source of bias to consider for results interpretation.

That is why, in 2016 censuses, to remediate to this problem, more effort was concentrated on size estimation. Underwater sheets with size indication per species were used by STV. Then, in 2016, there was no significant difference between large proportion-SD and large proportion-STV, in all locations, in all zones. STV showed improvement in performing FAST method within 3 years. It can be interesting for them also to start to get used to other more training demanding methods such as transect with single width. This will for sure take time for calibration dives, but relying on volunteer for scientific monitoring, under scientific validation, seem to have a great potential in Tunisia, as long as volunteers are willing to dive.

The used multiple observer counts to validate STV results with SD ones is one among other presently in use to reduce the bias between the two observer groups (e.g. re-sampling areas with known quantities or using training datasets (Bird *et al.*, 2014). Moreover, statistical methods are presently in use to correct bias measurement between scientists and volunteer data (e.g. validation approaches by simple statistical comparisons, or hierarchical modeling) (Bird *et al.*, 2014).

Coastal fishing pressure: first assessment of illegal fishing

Illegal fishing is worldwidespread, affecting all fishing activities (industrial, artisanal and recreational) (Tunca *et al.*, 2016). In Tunisia, fishing activities are concentrated mostly on the

coastal zones since 80% of the fleet is composed of small boats (Tunisian ministry of Agriculture, 2015) operating near the shores during maximum 3-days trips. Coastal fishing surveys showed three categories operating in the three studied locations, commercial small-scale fishing (CSS) or artisanal fishing (using nets or longline), recreational fishing (REC, using speargun, trolling or lines) and illegal fishing (IF, illegal fishers were defined as recreational who declared selling the catch).

Catch landed monitoring showed high trophic level catches, high intrinsic vulnerability species for all fishing categories. There was no significant difference between all fishing categories meaning that all of them are impacting for the fish assemblage. However, mean catch per fishing operation of IF was significantly higher than mean catch of CSS and REC. Moreover, IF caught very high economic value fish in comparison to CSS which made mean catch price (MCP) per kg for IF significantly twice higher than CSS one. The presence of illegal fishing is usually related to difficult socio-economic conditions of fishers that want to maximize their profit from fishing activities without expenses. This is creating unfair competition with the two other legal fishing activities and especially with CSS fishing. Pressure exerted on the coastal fish assemblage is alarmant, especially that catch included high predator level species, especially that 70% of these species were sized under their maturity length.

Illegal fishing is very problematic all along Tunisian coasts and must be highly considered in the three future MPAs. To achieve MPAs goals, when the protected areas constitute a fishing zone, it is essential to involve active fisherman. Taking into account the “human dimension” in management planning is a determinant component in MPAs goal achievement. Control in future MPA should focus on illegal fishing and poaching combat which is very likely to happen even in well protected MPAs (Tunca *et al.*, 2016; Lloret, 2016; Bergseth *et al.*, 2017).

When illegal fishing is caused by difficult socio-economic conditions of fishers, the combat is more difficult. In most of the cases, rising awareness and communication, cooperating with fishers (legal who can balance in illegal practice and illegal ones) for monitoring and conservation planning are perceived as an alternative solution (Guidetti *et al.*, 2008; Di Franco *et al.*, 2014). This is a long and difficult process to implement in the beginning, because usually, fishers were not used to be involved in decision making processes (PISCO & UNS, 2016) and in scientific monitoring. During our questionnaires, some fishers were willing to help us to monitor landed catches. It is

important to keep contact with these fishers, who are aware of the importance of scientific monitoring and concerned about marine protected areas and conservation issues. These fishers can be called as “key” fishers, who can constitute the “relay points” between local fishers and other MPAs managers, decisions makers and scientists.

Our results highlight the urgent need of fishing law application (Minestrial Decrees in 20th of September 1994 and 28th of September 1995) regarding the exercise of recreational fishing, to reduce quickly the scale of illegal fishing and its competition with CSS fishing. Then, once MPAs are created and protection is effective, ecological effect of artisanal fishing in the allowed fishing zones should also be monitored to evaluate fishing operations and their impact on the fish assemblages. With the elimination of illegal fishing, an increase in catch economic value is expected for CSS fishing (Prato *et al.*, 2017).

Other fishing monitoring methods

Experimental fishing applied in the same three locations showed low caught biomasses, the ones that are comparable to other fished areas in the Mediterranean Sea. Then, carnivores proportions in biomass, that are more valuable and appreciated, are with very low percentages in all locations. Frequencies size of large fish are also low. No significant difference was found between inside and outside each location. Experimental fishing can be of great interest for cooperation in monitoring and management processes.

From the other hand, for Zembra and Zembretta, we proposed also the photography for the surveillance method. Which consists on the use of an autonome camera programed to take photos 3 times per hour continuously for 20 days. Then battery and memory cards changes are necessary to persue the photographing. The advantage of this method is to provide continuously useful material (photos) to exploit and to get data about frequentation by users and concentration spots of fishing, recreation, anchoring...etc, at low cost. Indirect information that can be derived from this support can be useful for control needs.

Further discussions: fish and fisheries monitoring plan proposed

Tunisian future MPAs are being created to assure biodiversity conservation and sustainable economic activities. For instance, in Kuriat, the objectives are to enhance CSS fishing and tourism, in Cap Negro Cap Serrat, to promote CSS fishing and to enhance other sustainable economic

activities for local population, and for Tabarka, to enhance recreational diving and CSS fishing. The promotion of CSS fishing activity is one of the priorities in management plans in all future MPAs. The implementation of the MPAs will limit the exploitation of resources. Restrictions will affect for sure CSS fishermen with their difficult economic situation, already weakened by the lack of fishing resources (DGPA, 2016). The effort of creating MPAs is also dedicated to the preservation of CSS fisher interests, who are suffering from conflicts with recreational and illegal fishers.

The involvement of fishermen, throughout their collectivities or through “key” fishermen, is considered as crucial for the co-management process designed for MPAs. Using training and workshops on marine protected areas, reserve effect and sustainable development, can help setting up a favorable climate to the acceptance of the protected area. Our work about fishing activities monitoring can be considered as the first step toward the “Participatory Development Plan for Fisheries” (RAC/SPA & PNUE-PAM, 2015) which is a part of Management Plans. The Participatory Development Plan will be based on two components: compliance between people to the principles of co-management of resources, and the sustainable development of fisheries.

Our work is also among the firsts that involved CSS and recreational fishers in scientific monitoring. Proposed and applied methods, in some way, helped to raise the communication level between CSS fishermen and the scientist. Which is a critical component to MPA success (Claudet & Guidetti, 2010; Guidetti *et al.*, 2008; Di Franco *et al.*, 2016; Arceo *et al.*, 2013). Thus, the implementation of volunteer monitoring projects where fishers actively participate are becoming common around the world, and can play a role in achieving higher rates of MPA acceptance and success (Lloret *et al.*, 2012; Batista *et al.*, 2015). All stakeholders, including fishermen, can be engaged in the governance, convincing one another, and promoting a high level of compliance and social acceptance of MPAs. MPAs staff, decision makers, scientists, recreational divers and fishers (professional and recreational) should all work together even before MPA creation and after for the realization of the management plan, to give the MPA all its chances to be effective (e.g. Côte bleu marine park) (PISCO & UNS, 2016).

To assess reserve effect, three metrics are usually used: biomass, density and body size (e.g. Guidetti *et al.*, 2014; Harmelin-Vivien *et al.*, 2008). Other scientists used other proxies for density and species richness such as FAST indicators (Seytre & Francour, 2008; 2009). Within our work, we showed that these proxies can be complementary to the other metrics. The proposed and

applied methods for fish assemblages were chosen specifically to the Tunisian context. In the following section, we propose a fish and fishing monitoring strategy for Tunisian MPAs. It is presented using two schemes following three levels of time scale (short term: urgent actions/ before MPAs creation, midterm: maximum in the two years after MPAs creation, long term: in two to four years after MPAs creation), according two main objectives:

Objective 1: to assess fish assemblage spatial and temporal variability underwater using UVC methods

In the short term, two activities are proposed. The first one is to assess fish assemblage variability underwater by calculating exhaustive metrics: biomass, density and fish size distribution, using the standard method of transects with variable width (TVW). This method should be performed following the same sampling scheme used in this work i.e. inside and outside the protected zones, with the same habitats conditions, with sufficient spatial and temporal replication, during the warm season. In the short term, scientists should perform it. Given the training demanding and the difficulty to perform this method, its application each two years should be enough to assess variability if enough replication is applied. Metrics calculated from this method are exhaustive and sensitive to management measures that will be applied (protection, fishing banning, and others). The second UVC method proposed is the easy-to-use method FAST. It should be applied more often with the help of Scientifically Trained Volunteers (STV) under scientific supervision. From our results, FAST indicators calculated can be used as proxies for density, species richness and size distribution for commercially relevant species concerned with the method. This method should be applied in the same sampling sites as TVW method with the same habitat conditions. We suggest applying this method each year during the warm season, with available STV.

In the midterm, fish monitoring questions should be addressed with wider vision in larger scales. We should consider enlarging the circle of divers able to perform UVC methods, beginning with training MPAs managers, then recreational divers. Starting with easy-to-use method FAST could encourage volunteers to perform it at the same time they perform recreational diving. It is also preferable that MPAs managers get a training on fish monitoring using UVC because it is the first way to evaluate the results of their work i.e. MPA effectiveness (Guidetti *et al.*, 2014 and references within). In a second step, from our experience, citizen science can be a promoting

solution to the lack in scientific divers with training and scientific validation of results, citizen science applied for fish monitoring, as applied in all the world (Edgar *et al.*, 2014) can be a very useful tool for Tunisian MPAs. For non-experimented STV, training should be done in multiuse zones or in other fished areas.

On the long term, and based on common efforts of scientists, managers and STV, 5 years of planning should take place in all Tunisian MPAs to ensure a good covering for fish assemblage variability along MPA network. Using this strategy, wa can move forward from small scale fish monitoring, with limited number of SD to large scale fish monitoring with the help of volunteers. This could strengthen their acceptance and engagement to MPAs objectives.

Objective 1: to assess fish assemblage variations metrics in Tunisian MPAs each year

	Activities	methods	Sites	Who	Frequency	replication	Time needed	
Short term	Activity 1 : to calculate biomass, density and size distribution of fish assemblage	Transect with Variable Width (TVW)	2 or 3 sites in each zone, depth between 10 and 20 meter	Scientist, managers, volunteers, after training	One time per 2 years	3 replicates per transect width and per site	45 min per site, one observer	
	Activity 2 : to calculate FAST indicators and assessment groupers and brown meagre with size estimation	FAST method	2 or 3 sites in each zone, depth between 10 and 20 meter	Scientist and STV	One time per year	6 replicates per site	90 min per site split on the number of observers	
Mid-term	Activity 3: training MPAs managers on FAST and on transect method	Theoretical and calibration dives	Multi-use zones	Scientist (trainer)	Depending on availability	6 replicates per site	1 day for FAST and 4 days for transects	
	Activity 4: training other volunteer divers on FAST and STV on transect method	Theoretical and calibration dives	Multi-use zones	Scientist (trainer)	Depending on their availability	3 replicates per transect width and per site	1 day for FAST and 4 days for transects	
Long term	Activity 5: After testing the bias between observers, plan the UVC campaign in all MPAs	TVW and FAST	2 or 3 sites in each zone, depth between 10 and 20 meter	Scientist, managers, volunteers	Each year	3 replicates per transect width and per site	-	

Objective 2: The second objective of the proposed monitoring strategy is to assess continuously fishing activities in MPAs.

Since data about coastal fishing are not available in all MPA, on the short term, three activities are necessary. First, frequentation survey with patrol and autonomous photography method should take place in protected and fished zones (as proposed for Zembra and Zembretta). This last method could be very useful to control poaching, which is very likely to happen in an MPA (Bergseth *et al.*, 2017). Secondly, using the results of the first activity, it will be possible to define coastal fishing practioners, which is a very important step. Coastal fishing users are an important category to consider for management planning. basing on our results, this step led to describing illegal fishing in the three studied MPAs, which is very relevant, this category being the most impacting and difficult to combat activity. The third urgent activity is to monitor landed catch for all fishing categories in future protected and fished zones. It is crucial that the collected data contains a maximum of information, including precise species identification and their size. Which was not included in official data of fisheries departements in the ministry of agriculture. This information is of a great relevance to assess effects of MPAs (Di Franco *et al.*, 2016).

During our work, we started a participative approach with CSS fishermen and recreational fishers to help monitor catch landed. In the mid and long term, this should be continued through experimental fishing method, and the organization of training and meetings with fishermen. Networking with these most concerned people by MPAs creation and functioning can be a practical solution toward co-management in Tunisian MPAs. As for fish assemblage monitoring, fishing activities monitoring can be implemented on the large scale using working side by side with fishermen in a practical way, by helping them on fishing operation, asking for local knowledge and for their help in scientific monitoring. This would be of a great potential. From other Mediterranean experiences (Nueva Tabarka), confrontation with fishermen could be inevitable. But the matter can be to reduce this confrontation impact on MPA creation and functioning through the involvement of “key” fishermen that can spread out their pro MPAs ideas to others.

Using the same methods for all future MPAs has the advantage of allowing the assesement of connectivity from one MPA to another (Calò *et al.*, 2013), case of Tabarka and Cap Negro Cap Serrat, proximity the one from the other. Given their geographical position and the ressemblance in their bottoms, their meteorological condition, since they are both in the north. In all locations, the

absence of significant differences in fish assemblage metrics inside and outside locations, low high trophic level predator's densities and biomasses and high frequencies of small sized classes commercial fish suggests the high fishing pressure exerted in these areas. The matter of establishing a network of MPAs along the Tunisian coasts is proposed since the year 2000 by the Tunisian government. However, to ensure the effectiveness of this network, single MPAs should be effective and performant, with monitoring of changes in fish assemblages, fisheries enhancement, species range extensions (Roff, 2014). The same patterns should be measured within the network to demonstrate the 'outcomes' of a real network. Then, in the future, there is the far more difficult challenge of demonstrating that a true network of MPAs is actually achieved and is effective (Roff, 2014).

Objective 2: To assess coastal fishing activities in Tunisian MPAs each year

	Activities	methods	Sites	Who	Frequency	material needed	
Short term	Activity 1 : frequentation survey,	Patrol, autonomous photography	Protected and non-protected zones	Scientists, managers,	Two weeks per season, or continuously	Boat, or camera with external battery	Spatial scale increase ↓ large scale Sampling: MPA network
	Activity 2 : defining coastal fishing practitioners	Questionnaire	Protected and non-protected zones	Scientists, managers and volunteer fishers	Two weeks per season	Boat	
	Activity 3: monitoring catch landed for each fishing activity (including catch size)	Questionnaire or photo with scale	Protected and non-protected zones	Scientists, managers and volunteer fishers	Two weeks per season	With or without boat	
Mid- term	Activity 4: monitoring CSS catch and communicate with fishermen	Experimental fishing	3 sites Fished zones and 3 sites borders of protected zones	Scientists and managers	Twice per year, 3 replicates per site	Weight balance, ruler,	
Long term	Activity 5: networking with fishermen about fishing monitoring and invasive species	Organizing trainings and meetings with “key” fishers and others	All MPAs included	Scientists, communication expert and managers	Once per year	Communication strategy	

Perspectives

❖ Legal status processing... apply the existing laws?

MPA creations processes are very slow, since the year 1998, efforts were made in this direction. The law was decreed only 9 years later. Besides, there are many steps and conditions to fulfill. The problem is that it is not possible to start protecting without a juridic background. However, regarding the urgency of protection needed in the studied locations, one quick solution can be to start protecting future no-take zones, as small MPAs that can be also effective for fish species (PISCO & UNS, 2016). Protecting smallest areas, can be more faisible and practical, easier to patrol, to control and to assess effectiveness. Promulgating minestrial decrees can take much less time than waiting for the law. Surface in protecting is not that determining in comparison to the importance of control.

❖ Determining other factors of variation in fish assemblage metrics? Quantify the influence of landscape complexity on fish assemblages?

Variations in fish assemblage in MPAs can be due to protection when experimental design is properly applied. It can be also due to other factors, such as seasonality, habitat complexity or seascape variations. Variations in seascape complexity (based on seascape structural spatial pattern metrics) might create optimal or suboptimal conditions for various fish assemblages (Staveley *et al.*, 2016). Seascape heterogeneity is recognized as a central driver to many ecological processes ; Studies applying seascape spatial approaches to explain fish assemblage's variability in tropical (Darling *et al.*, 2017) and cold-temperate (Staveley *et al.*, 2016) marine systems indicate that seascape structure likely play an important role in determining fish community composition, abundance and species richness (Staveley *et al.*, 2016).

In Marine Protected Areas (MPAs), reserve effect" on fish assemblages was demonstrated in many well managed MPAs (Guidetti *et al.*, 2014). However, reserve effect should be distinguished from other factors effects such as physio-chemical factors and habitat seascape heterogeneity, which can mask our ability to discern reserve effects (Huntington *et al.*, 2010). The question of variability of fish assemblage structures under protection or under seascape complexity has been asked many

years ago, highlighting the relative importance of habitat structure, considered as a set of biological and physical elements of the seascape hierarchically arranged in space at multiple scales, to drive natural variability. Characterization of spatial heterogeneity in relation to Mediterranean MPAs, and quantifying relationships between fish species and their habitats are crucial to explain variabilities in fish assemblage's patterns and metrics (García-Charton *et al.*, 2000). Thus, for studied Tunisian locations, quantifying seascape integrity (Thorin *et al.*, 2014) or seascape complexity can be a forward step. For example, in Kuriat islands and Tabarka, sites BIO19 and BIO11, and TU (See Supplementary Material III.3) are characterized by the presence of large cavities and. In Cap Negro-Cap Serrat, there were no such sites. This difference can be driven natural differences between these sites which will be no-take zones, and the others, multi-use and no-protected areas. That is why, further quantification using exhaustive methods should be applied in the same sites to explore the relationship seascape complexity, fish abundance, biomass and protection.

❖ Testing the performance of STV for standard methods (transects)?

Participatory science is part of this work is proposed as an effective way to collect useful data on fish stocks in future AMPs studies. The method used by STVs so far is the FAST method which provides a minimum of missing presence information with indication of the size class. Given the potential for involvement of volunteer divers in follow-up in 84 AMPs around the world (Edgar *et al.*, 2014), learning and applying more exhaustive methods would be interesting to test.

❖ How coastal fishing impact coastal fish assemblages: the use of coupling empirical data with modelisation?

So far, in the future MPAs studied, the definition of the current situation and the ecological and socio-economic dimensions of inshore fishing activities have been explored. Subsequently, the impacts of different fishing categories on fish assemblages (e.g. species and most impacted categories) have not been explored before. For this, modeling using empirical data (Pelletier *et al.*, 2008) could provide information on scenarios for the exploitation and regulation of coastal fishing activities. This may be useful for managers of future MPAs (Prato *et al.*, 2016), who may even decide to communicate scenarios to fishermen.

❖ Explore and determine the relation between illegal fishing and socio-economic factors?

Consisting in defining more closely the relationship between illegal fishing and socio-economic factors in "pilot" zones in Tunisia and in other southern and eastern Mediterranean countries. It has been assumed that illegal fishing in developing countries is favored by difficult socio-economic conditions (Drammeh *et al.*, 2012, FAO, 2016). However, this point has not been explored at more local scales to see the direct or indirect causal relationship between socio-economic factors and the incidence of illegal fishing. This is far from easy to determine. On the other hand, given the strong interdisciplinarity in MPAs, it would be useful to try to explore these relationships and their relationships within MPAs.

Chapitre VIII : Discussion générale

Questions initiales

Dans le milieu marin, et en particulier dans les AMPs, Le suivi scientifique est une étape clé pour obtenir des informations fiables. En utilisant des méthodes adéquates et des designs expérimentaux, les données empiriques recueillies sur le terrain sont la première source d'information fiable pour calculer les métriques et les indicateurs, ce qui représente une étape cruciale pour la gestion des zones côtières. Dans les AMPs, le suivi scientifique doit être bien adapté aux objectifs de conservation et de gestion (Albright *et al.*, 2016). Les futures AMPs de la Tunisie sont des zones côtières qui subissent de multiples pressions humaines mais qui abritent une biodiversité exceptionnelle (CARASP & PNUE-PAM, 2014 ; Zarrouk, 2017).

La loi de 2009 stipule les conditions et les exigences pour promulguer la création d'AMPs. Le « Conseil national pour les Aires Marines et Côtières Protégées (AMCP) » a été créé par le décret Ministériel du 28 avril 2017 (JORT n° 34 du 28 avril 2017, conformément à la loi n° 2014-1844 du 19 mai 2014 sur sa création, sa composition et la mission. Cela signifie que le décret de création de l'AMP sera prochainement promulgué. Les suivis scientifiques réalisés dans le cadre de ce travail depuis 2014, pendant trois ans, ont été réalisées avant la création légale des AMPs.

Comme dans de nombreux pays méditerranéens, les AMPs tunisiennes sont créées non seulement pour protéger la biodiversité, mais aussi pour promouvoir les activités socioéconomiques importantes (CAR/ASP & PNUE-PAM, 2014, 2015). De ce fait, le suivi scientifique dans les AMPs devrait concerner aussi bien les ressources biologiques et écologiques que les activités socio-économiques ayant un impact (par exemple, le tourisme, la plongée récréative, la pêche professionnelle et récréative) (CAR/ASP & PNUE-PAM, 2015).

Dans de nombreuses AMPs méditerranéennes, l'effet de la protection ou effet réserve a été évalué à l'aide des suivis des peuplements de poissons par comptages visuels sous l'eau (UVC) à l'intérieur et à l'extérieur des AMPs (e.g. Côté *et al.*, 2001 ; García-Charton *et al.*, 2004 ; Claudet *et al.*, 2006 ; Guidetti & Sala, 2007; Lester *et al.*, 2009; Aburto-Oropeza *et al.*, 2011, 2015, Hackradt *et al.*, 2014; Guidetti *et al.*, 2014). Idéalement, pour évaluer l'effet réserve, il est préférable d'appliquer un design expérimental comme décrit dans Guidetti *et al.*, 2002, qui tient compte de la collecte des données aussi bien avant qu'après la création des AMPs (Guidetti *et al.*,

2002 ; Pauly *et al.*, 2008), à l'extérieur et à l'intérieur, dans différentes zones (zone de non-prélèvement ou zone de protection intégrale et zone non protégée ou zone pêchée). Il est préférable de faire les recensements durant la même saison, dans les mêmes sites ayant des caractéristiques d'habitat et de profondeur similaires, pour permettre des comparaisons statistiques fiables, les effets de saisonnalité et d'habitat pouvant masquer l'effet réserve (Garcia-Charton *et al.*, 2000).

L'objectif de notre travail était de sélectionner, adapter, proposer et tester des méthodes et indicateurs de suivi des peuplements de poissons et des pressions de pêche et d'assemblage de poissons pour quatre futures AMCPs tunisiennes afin de proposer une stratégie de suivi pour la pêche et la surveillance de la pêche pour les AMPs tunisiennes. La sélection des indicateurs de la littérature a été réalisée en fonction de leur faisabilité, de leur rentabilité et de leur adéquation avec les objectifs de suivi. Cinq méthodes ont été appliquées : deux méthodes de suivi par recensement visuel (UVC) et trois méthodes de suivi des activités de pêche. Les méthodes UVC appliquées comprennent une méthode standard (transects avec largeur variable (TVW)) qui a été utilisée pour collecter des données exhaustives en comptant tous les poissons rencontrés avec une précision de classe de taille de 1 à 5 cm (Prato *et al.* 2017) et une méthode facile à utiliser (méthode d'échantillonnage d'assemblage de poissons (FAST), basée sur la présence / absence à l'aide d'une liste pré-établie) utilisée avec des plongeurs bénévoles après une formation scientifique. Les méthodes de suivi de la pêche testées étaient les questionnaires et le suivi des débarquements, la pêche expérimentale et la photo-surveillance. Ainsi, selon l'objectif de notre travail, plusieurs hypothèses correspondant à des sous-objectifs ont été testées :

S / objectif 1 : mettre en place un design expérimental « Before Impact » pour trois futures AMPs en utilisant une méthode standard (transects de largeurs variables)

Hypothèse 1. Existe-t-il une différence significative entre l'intérieur (future zone protégée) et l'extérieur (zone non protégée) dans les métriques des assemblages de poissons (densité, biomasse, richesse spécifique et fréquence des classes de taille) ?

S / objectif 2 : Devant le manque de données dans les zones côtières et le manque de plongeurs scientifiques, proposer, adapter et tester une méthode facile à utiliser applicable par les plongeurs bénévoles

Hypothèse 2. La méthode UVC standard est-elle comparable à la méthode UVC facile à utiliser (FAST) ?

Hypothèse 3. En appliquant la méthode FAST, les résultats des plongeurs volontaires ayant suivi une formation scientifique (STV) sont-ils significativement différents du plongeur scientifique (SD) ?

S / objectif 3 : Devant la pression de la pêche côtière : comprendre les dimensions écologiques et socio-économiques de la pêche côtière en Tunisie ainsi que la part de la pêche illégale.

Hypothèse 4. En utilisant les questionnaires et le suivi des débarquements : Existe-t-il une différence significative entre les catégories de pêche côtière (artisanale, récréative et illégale) en utilisant la capture moyenne, le niveau trophique moyen (MTL), l'indice de vulnérabilité intrinsèque (IVI) et le prix moyen des captures (MCP) ? Et comment varient ces indicateurs avec le temps (variabilité saisonnière) ?

S / objectif 4 : tester la méthode de pêche expérimentale

Hypothèse 5. Existe-t-il une différence significative entre l'intérieur (future zone protégée) et l'extérieur (zone non protégée) dans les métriques de la pêche artisanale (biomasse, richesse spécifique, proportion de grande taille (LP) et proportion de carnivores (CP)) ?

S / objectif 5 : tester la méthode de surveillance par photographie

Principaux résultats

Design expérimental « Before impact » pour évaluer l'efficacité des AMPs à l'aide de suivis par recensement visuel standardisé

La méthode standard utilisée, celle des transects à largeurs variables (TVW), permet le recensement de toutes les espèces de poissons avec précision. Le fait de compter 3 groupes de

poissons dans des transects de longueur et de largeur différentes, en tenant compte de leurs comportements et de leurs tailles maximales, augmente l'efficacité et la précision des comptages. En utilisant cette méthode, on considère même les espèces cryptiques qui ne sont généralement pas comptées en utilisant un transect de largeur unique (Prato *et al.* 2017). En effet, le plongeur est plus concentré sur le comptage d'autres poissons mobiles dans la colonne d'eau. L'application de cette méthode requiert une très bonne connaissance en identification des poissons jusqu'au niveau de l'espèce ainsi qu'une bonne expérience en comptage. En comparaison avec les transects de largeur unique, TVW a montré plus d'efficacité pour le comptage des prédateurs de hauts niveaux trophiques ou de grandes tailles (Ex. *Epinephelus marginatus*, *Sciaena umbra*, *Sphyraena viridensis*, *Dentex dentex* et *Mycteroperca rubra*) dans les AMPs de Cabo de Palos, Scandola et Tavolara (Prato *et al.*, 2017).

Dans le cadre de notre travail, en utilisant les TVW, un design expérimental « Before Impact », formellement répliqué dans le temps et dans l'espace a été proposée pour les trois futures AMPs afin de tester leur efficacité (effet réserve) une fois qu'elles seront décrétées et officiellement protégées. La composition des taxons des assemblages recensés dans les trois localités étudiées en Tunisie a montré que les poissons appartenant aux familles Sparidae, Labridae et Serranidae étaient les plus représentés en termes de nombre d'espèces, (e.g. Seytre & Francour, 2014, García-Charton & Pérez-Ruzafa, 2001). La distribution des peuplements de poissons dans les futures AMPs et les sites (non protégés, protégés dans le futur) en termes de densité et de biomasse était assez variable dans le temps et dans l'espace. Les modèles observés peuvent être attribués à des facteurs indépendants de la protection, tels que les distributions de type d'habitat, la pente, la couverture d'algues, la rugosité inférieure ou la complexité du paysage marin (voir Garcia-Charton *et al.*, 2000) qui n'ont pas été pris en compte dans la présente étude. A l'avenir, ce résultat doit être pris en compte dans tous les suivis. Il souligne une fois de plus l'utilité de l'adoption de modèles d'échantillonnage appropriés, notamment le design expérimental « Before Impact », dans le cadre des designs expérimentaux BACI (« Before After Control Impact »), pour tester correctement les hypothèses liées à l'efficacité des AMPs (Guidetti, 2002; Pelletier *et al.*, 2008; Bonaldo *et al.*, 2017).

Notre étude peut être considérée comme un point de référence important pour évaluer à l'avenir l'état des assemblages de poissons le long des côtes de la Tunisie et les effets des mesures de protection qui seront introduites après la mise en œuvre prévue des trois AMPs. En outre, cette étude pourrait déclencher d'autres recherches dans d'autres pays au sud de la méditerranée et en Méditerranée orientale. Cela permettra une évaluation plus exhaustive des effets des AMPs qui seront implémentées dans la région compte tenu du grand déséquilibre en études entre ces deux régions et le nord-ouest de la Méditerranée (PISCO & UNS, 2016, Giakoumi *et al.*, 2017).

Le suivi des assemblages de poissons en Tunisie : L'utilité des sciences participatives : Challenges et perspectives

La méthode standard des transects de largeurs variables est indispensable pour collecter des données exhaustives (Prato *et al.*, 2017). Cependant, pour le contexte tunisien (zones peu étudiées), il est essentiel d'intensifier l'effort de suivi des assemblages de poissons. Les programmes de suivis traditionnels, appliqués jusqu'ici, sont limités par les financements et les plongeurs scientifiques disponibles, ce qui a entraîné de nombreuses lacunes au fil des années. Dans ce contexte, le recours aux sciences participatives est perçu comme une solution rentable. Les plongeurs récréatifs impliqués dans le suivi des peuplements de poissons dans les trois AMPs d'études n'ont pas appliqué TVW, mais plutôt une méthode facile à utiliser et à faible besoin en formation. C'est la méthode FAST (« Fish Assemblage Sampling Technique »), basée sur la présence / absence des poissons à partir d'une liste préétablie adaptée pour la Tunisie. En effet, les méthodes standard nécessitent une formation longue sur l'identification des espèces et surtout sur l'estimation de la taille des poissons sous l'eau (Edgar *et al.*, 2014, Aburto-Oropeza *et al.*, 2015). Les plongeurs récréatifs ont reçu une formation scientifique sur l'identification des espèces ciblées par la pêche (qui sont généralement faciles à identifier sous l'eau). Avant d'utiliser FAST, nous avons testé sa cohérence avec TVW. En utilisant le même design expérimental. TVW et FAST ont montré les mêmes patrons entre les sites et les zones pour tous les métriques et les indices au fil du temps. Toutefois, en utilisant TVW, toutes les interactions entre les facteurs étaient significatives pour l'indice des poissons de grande taille (LP), alors qu'une seule interaction était significative en utilisant FAST. Cette différence peut s'expliquer par la différence dans l'estimation de la taille en utilisant les différentes méthodes. En effet, avec FAST, l'estimation de la taille d'une espèce se fait

seulement par classe de taille (petites, moyennes et grandes) alors qu'avec TVW, une estimation de taille plus précise est effectuée (à une précision de 1 à 5 cm). A l'exception de cette différence, il a été considéré que les deux méthodes sont cohérentes dans la description des modèles entre les sites, entre les futures zones protégées et celles à l'extérieur. Cette cohérence suggère la proposition de la méthode FAST pour le suivi des assemblages en tant que complément pour TVW.

L'application de FAST par les plongeurs volontaires a été possible après une formation théorique et quelques plongées de calibration (les plongeurs récréatifs sont appelés STV pour « Scientifically Trained Volunteers »). Les résultats n'ont montré aucune différence significative entre les résultats du STV et le SD (Scientific Diver), à l'exception de l'indice de la richesse en espèces de Cap Negro-Cap Serrat et de l'indice de proportion des poissons de grande taille (LP) en 2014 et 2015. L'estimation de la taille des poissons sous l'eau est une source importante de biais à considérer pour l'interprétation des résultats. C'est pour cela que, dans les comptages de 2016, pour remédier à ce problème, plus d'efforts ont été concentrés sur l'estimation de la taille. Des plaquettes sous-marines avec indication de la taille par espèce ont été utilisées par les STV. Les résultats n'ont comporté aucune différence significative entre une LP-SD et LP-STV, dans toutes les futures AMPs, les STV ont montré une amélioration dans l'application de FAST au fil des années (sur les 3 AMPs chaque année). Il pourrait être intéressant pour eux de commencer à s'habituer à d'autres méthodes plus difficiles d'application telles que les transects de largeur unique. Cela prendra certainement du temps pour les plongées de calibration, mais les sciences participatives pour le suivi des peuplements de poissons, sous validation scientifique, semblent avoir un grand potentiel en Tunisie.

Le nombre d'observateurs multiples utilisés pour valider les résultats des STV avec les SD est actuellement utilisé pour réduire le biais entre les deux groupes d'observateurs (exemple : échantillonnage de zones avec des quantités connues ou utilisation d'ensembles de données de formation (Bird *et al.*, 2014). Des méthodes statistiques sont actuellement utilisées pour corriger la mesure du biais entre les scientifiques et les données des volontaires (par exemple, les approches de validation par des comparaisons statistiques simples ou une modélisation hiérarchique) (Bird *et al.*, 2014).

Les dimensions de la pêche côtière dans les 3 futures AMPs : première évaluation de la pêche illégale

Dans le monde entier, la pêche illégale affecte toutes les activités de pêche (industrielle, artisanale et récréative) (Tunca *et al.*, 2016). En Tunisie, les activités de pêche se concentrent principalement sur les zones côtières puisque 80% de la flotte est composée de petites embarcations (Ministère de l'agriculture tunisien, 2015). Les enquêtes sur la pêche côtière ont montré trois catégories opérant dans les trois futures AMPs : la pêche artisanale (CSS), la pêche récréative (REC) et à la pêche illégale (IF). Le suivi des débarquements a montré des captures de niveaux trophiques élevés et des captures d'espèces de vulnérabilité intrinsèque élevées pour toutes les catégories de pêche. Il n'y a pas eu de différence significative entre toutes les catégories de pêche, ce qui signifie que toutes ont une incidence sur l'assemblage de poissons. Cependant, la capture moyenne par opération de pêche de l'IF était significativement plus élevée que la capture moyenne de CSS et de REC. En outre, les captures de l'IF avaient une valeur économique significativement deux fois plus élevée que celles de CSS. La présence de la pêche illégale est généralement liée aux conditions socio-économiques difficiles des pêcheurs récréatifs qui veulent maximiser leurs bénéfices tout en minimisant les charges. Cela crée une concurrence déloyale avec les deux autres activités de pêche légales et surtout avec la CSS.

La pêche illégale est très problématique tout au long des côtes tunisiennes et doit être très appréciée dans les trois futures AMPs. Pour atteindre les objectifs des AMPs, lorsque les futures zones protégées constituent une zone de pêche, il est essentiel d'impliquer les pêcheurs, surtout ceux intéressés et conscients par la nécessité de la conservation. La prise en compte de la dimension humaine dans la planification et la gestion est une composante essentielle dans la réussite des objectifs des AMPs. Le contrôle à l'avenir d'une AMP devrait se concentrer sur la pêche illégale et le combat contre le braconnage. Lorsque le braconnage est causé par des conditions socio-économiques difficiles, le combattre est plus difficile. Dans la plupart des cas, la sensibilisation et la communication sont de plus en plus importantes. Il est essentiel de collaborer avec les pêcheurs lors de la mise en place de l'AMP pour le suivi des ressources et la gestion. Il s'agit d'un processus long et difficile à mettre en œuvre au début car initialement les pêcheurs n'avaient pas l'habitude d'être impliqués dans les processus décisionnels et dans le suivi scientifique. Au cours des enquêtes,

certaines pêcheurs étaient prêts à contribuer au suivi de leurs débarquements. Il est important de rester en contact avec ces pêcheurs qui sont convaincus de l'importance de la mise en place d'AMPs, du suivi scientifique et des préoccupations concernant les aires marines protégées. Ces pêcheurs peuvent être appelés « personnes ressources ». Ils peuvent constituer le lien avec d'autres pêcheurs locaux et les gestionnaires d'AMPs, les décideurs ou les scientifiques. Le même raisonnement peut être valable pour d'autres usagers des AMPs, tels que les clubs de plongée récréative (cas de la future AMP de Tabarka). C'est un processus qui peut être long à mettre en place, mais qui est faisable en adoptant les bonnes approches de communication afin de renforcer l'adhésion et l'appropriation des parties prenantes dans les futures AMPs tunisiennes (PISCO & UNS, 2016, Di Franco *et al.*, 2016).

Nos résultats mettent en évidence le besoin urgent d'appliquer des lois tunisiennes (décret du 20 septembre 1994 et décret du 28 septembre 1995) relatives à l'exercice de la pêche récréative afin d'arrêter rapidement la pêche illégale et sa concurrence déloyale avec la pêche artisanale. Une fois que les AMPs auront été créées et que la protection sera effective, l'impact de la pêche artisanale dans les zones de pêche autorisées devra également être suivi pour évaluer les opérations de pêche et leur impact sur les assemblages de poissons. Avec l'élimination de la pêche illégale, une augmentation de la valeur économique des captures peut être prévue pour la pêche artisanale (Prato *et al.*, 2017).

Autres méthodes de surveillance de la pêche

La pêche expérimentale appliquée dans les mêmes trois futures AMPs a montré de faibles biomasses capturées, comparables à d'autres zones pêchées en Méditerranée. Ensuite, les captures de poissons de hauts niveaux trophiques, plus précieuses et appréciées, présentent des pourcentages très faibles dans tous les endroits. La taille des fréquences des gros poissons est également faible. Aucune différence significative n'a été trouvée entre l'intérieur et à l'extérieur de chaque site. Bien que la série de données comprenne une seule campagne d'échantillonnage et une seule année, la pêche expérimentale peut être d'un grand intérêt pour la coopération dans les processus de suivi et de gestion.

D'autre part, pour Zembra et Zembretta, nous proposons également la photo-surveillance, qui consiste à utiliser une caméra autonome programmée pour prendre des photos 3 fois par heure en continu pendant 20 jours. Cependant, les changements de batterie et des cartes mémoire sont nécessaires pour poursuivre la photographie. L'avantage de cette méthode est de fournir des supports utiles (photos) pour le recueil et l'exploitation des données sur la fréquentation par les utilisateurs et les points de concentration de la pêche, des loisirs, de l'ancrage ... etc., à faible coût. Les informations indirectes qui dérivent de ce support peuvent être très utiles.

Autres discussions : Planning pour le suivi des activités de pêche côtière et des peuplements de poissons dans les futures AMPs Tunisiennes

Les futures AMPs tunisiennes seront créées pour assurer la conservation de la biodiversité et des activités économiques durables. Par exemple, à Kuriat, les objectifs sont de promouvoir la pêche artisanale et le tourisme, à Cap Negro-Cap Serrat, pour promouvoir la pêche artisanale et pour améliorer d'autres activités économiques durables pour la population locale. A Tabarka, il s'agit de promouvoir la plongée récréative et la pêche artisanale. La promotion de la pêche artisanale est l'une des priorités dans les plans de gestion dans toutes les futures AMPs. La mise en œuvre des AMPs limitera l'exploitation des ressources dans certaines zones tout en considérant la continuité de certaines activités économiquement importantes. Les restrictions affecteront les pêcheurs artisanaux avec leur situation économique difficile, déjà affaiblie par le manque de ressources halieutiques (CAR/ASP & PNUE-PAM, 2014 ; DGPA, 2016). L'effort de création d'AMPs est également consacré à la préservation des intérêts des pêcheurs CSS, qui souffrent de conflits avec les pêcheurs récréatifs et illégaux.

Dans les futures AMCPs tunisiennes, des plans de gestion, des restrictions et des zonages sont en cours d'élaboration. Le suivi scientifique de la pêche a été proposé comme une activité urgente et prioritaire (court terme), alors que le suivi des peuplements de poissons par recensement visuel a été seulement évoqué comme une activité à prendre en compte, sur le moyen terme après la mise en place de l'AMP (CAR/ASP & PNUE-PAM, 2015 ; APAL, 2010). Cependant, le suivi de l'assemblage de poissons est primordial pour évaluer l'efficacité d'une AMP donnée, à travers la mesure de biomasse, de la densité et la fréquence des classes de taille de

poissons (PISCO & UNS, 2016). Notre travail s'avère alors pertinent pour le contexte tunisien. D'une part, des données inédites sur les pêches côtières (artisanale, récréative et illégale) ont été recueillies et compilées pour obtenir des conclusions sur les activités de pêche dans les trois AMPs étudiées, ce qui correspond aux objectifs des plans de gestion. D'autre part, compte tenu de la pertinence relevée de la collecte avant les données d'impact pour le suivi des peuplements de poissons, les méthodes UVC appliquées permettront des comparaisons statistiques fiables pour évaluer l'effet réserve et la performance des futures AMCPs tunisiennes.

La participation des pêcheurs, dans l'ensemble de leurs collectivités ou à travers des pêcheurs « ressources », est considérée comme primordiale pour le processus de co-gestion conçu pour les AMPs. L'utilisation de la formation et des ateliers sur les zones marines protégées, les effets bénéfiques de la protection et le développement durable peuvent aider à créer un climat favorable à l'acceptation de l'aire protégée. Notre travail sur le suivi des activités de pêche peut être considéré comme la première étape vers le « Plan de développement participatif pour les pêches » (CAR/ASP & PNUE-PAM, 2015) faisant partie du plan de gestion. Le plan de développement participatif sera basé sur deux composantes : l'adhésion des pêcheurs aux principes de la cogestion des ressources et le développement durable de la pêche.

Notre travail est également parmi les premiers qui ont impliqué les pêcheurs artisanaux et récréatifs dans le suivi. Les méthodes proposées et appliquées ont permis d'une façon ou d'une autre d'augmenter le niveau de communication entre les pêcheurs artisanaux et les scientifiques. Cette communication peut contribuer au succès des AMPs (Claudet & Guidetti, 2010 ; Guidetti *et al.*, 2008 ; Di Franco *et al.*, 2016 ; Arceo *et al.*, 2013). Ainsi, la mise en place d'AMPs dans lesquelles les pêcheurs participent activement est de plus en plus fréquente dans le monde (Bergseth *et al.*, 2017) et peut jouer un rôle dans l'atteinte de taux plus élevés d'acceptation et de succès de l'AMP (Lloret *et al.*, 2012 ; Batista *et al.*, 2015, Di Franco *et al.*, 2016). Toutes les parties prenantes, y compris les pêcheurs, peuvent également participer activement à la gestion. Ils peuvent être engagés dans la gouvernance, et promouvoir l'acceptation sociale des AMPs. Le personnel de l'AMP, les décideurs, les scientifiques, les plongeurs récréatifs et les pêcheurs (professionnels et récréatifs) devraient tous travailler ensemble avant même la création de l'AMP et après pour œuvrer à la réalisation du plan de gestion, afin de donner à l'AMP toutes ses chances

d'être effective (par exemple, parc marin de la côte bleue et le parc marin de Jijel en Algérie (PISCO & UNS, 2016)).

Dans la section suivante, nous proposons un planning de suivi des peuplements de poissons et de la pêche pour les futures AMPs tunisiennes pour les gestionnaires. Il est présenté en utilisant deux schémas suivant trois niveaux temporels (court terme : actions urgentes / avant la création d'AMPs, à mi-parcours : maximum dans les deux années suivant la création de l'AMP, sur le long terme : dans deux à quatre ans après la création de l'AMP), selon deux principaux objectifs:

Objectif 1: évaluer la variation spatiale et temporelle des peuplements de poissons sous l'eau à l'aide de méthodes UVC

À court terme, deux activités sont proposées. La première consiste à évaluer la variabilité de l'assemblage des poissons sous l'eau en calculant les paramètres exhaustifs : la biomasse, la densité et la répartition des tailles des poissons, en utilisant la méthode standard de transects à largeur variable (TVW). Il est préférable que cette méthode soit effectuée selon le même design expérimental utilisé au cours de ce travail, à l'intérieur et à l'extérieur des zones protégées, avec les mêmes conditions d'habitat, avec une réplification spatiale et temporelle suffisante, pendant la saison chaude. À court terme, les scientifiques devraient l'effectuer. Compte tenu de la difficulté d'utiliser cette méthode, son application tous les deux ans devrait être suffisante pour évaluer la variabilité si une réplification suffisante est appliquée. Les métriques calculées à partir de cette méthode sont exhaustives et sensibles aux mesures de gestion qui seront appliquées (protection, interdiction de la pêche et autres). La deuxième méthode UVC proposée est la méthode facile à utiliser FAST. Il est possible de l'appliquer plus souvent avec l'aide de bénévoles après avoir suivi une formation scientifique (STV). À partir de nos résultats, les indicateurs FAST calculés peuvent être utilisés comme des proxy pour la densité, la richesse en espèces et la répartition des tailles pour les espèces commercialement pertinentes concernées par la méthode. Cette méthode devrait être appliquée dans les mêmes sites d'échantillonnage que la méthode TVW avec les mêmes conditions d'habitat. Il est suggéré d'appliquer cette méthode chaque année pendant la saison chaude, avec les STV disponibles.

Sur le moyen terme, le suivi des peuplements de poissons par recensement visuel devrait être abordé avec une vision plus large et à plus grande échelle. Nous devrions envisager d'élargir le cercle des plongeurs capables d'effectuer des méthodes UVC, en commençant par la formation des gestionnaires d'AMP, puis par les plongeurs récréatifs. Il est également préférable que les gestionnaires d'AMPs suivent une formation sur le suivi par recensement visuel, car c'est la première façon d'évaluer les résultats des mesures de gestion qu'ils prennent, c'est-à-dire l'efficacité de l'AMP. (Guidetti *et al.*, 2014, Guidetti, 2002). Dans un deuxième temps, la science citoyenne peut être une solution pour pallier le manque de plongeurs scientifiques, sous réserve de validation scientifique des résultats, comme cela est appliqué dans le monde entier (Edgar *et al.*, 2014). Cela pourrait être très utile pour les AMPs tunisiennes. Pour un STV non expérimenté, la formation devrait être effectuée dans des zones multi-usages ou dans d'autres zones non protégées.

Sur le long terme, et en fonction des efforts communs des scientifiques, des gestionnaires et des STV, une planification quinquennale devrait avoir lieu pour toutes les futures AMPs tunisiennes afin d'assurer une bonne couverture pour la variabilité des peuplements de poissons sur le réseau des futures AMPs tunisiennes. À l'aide de cette stratégie, on peut avancer depuis les suivis à petite échelle, avec un nombre limité de SD, au suivi à grande échelle avec l'aide de plus bénévoles. Cela pourrait renforcer leur acceptation et leur engagement envers les AMPs.

Objectif 1: évaluer les métriques des assemblages de poissons dans les AMPs tunisiennes

	Activités	Méthodes	Sites	Qui	Fréquence	Réplikat	Temps requis	
Court terme	Activité 1 : calculer la biomasse, densité et distribution des tailles des assemblages de poissons	Transects de largeurs variables (TVW)	2 ou 3 sites dans chaque zone, profondeur entre 10 et 20 mètres	Scientifiques, gestionnaires, volontaires, après formation	Une fois tous les deux ans	3 réplikat par largeur de transect et par site	45 min par site, un seul observateur	Echantillonnage à petite échelle: une ou quelques AMPs
	Activité 2 : calculer les indicateurs FAST avec suivi mérour et corbs avec estimation de la taille	FAST	2 ou 3 sites dans chaque zone, profondeur entre 10 et 20 mètres	Scientifique et STV	Une fois par an	6 réplikat par site	90 min par site divisé par le nombre d'observateurs	
Moyen terme	Activité 3 : formation des gestionnaires d'AMPs sur FAST et les transects	Théoriques et des plongées de calibration	Zones multi-usages	Scientifique (formateur)	Dépendant des disponibilités	6 réplikat par site	1 jour pour FAST et 4 jours pour TVW	
	Activité 4 : formation d'autres plongeurs volontaires sur FAST et des STV sur les transects	Théoriques et des plongées de calibration	Zones multi-usages	Scientifique (formateur)	Dépendant des disponibilités	3 réplikat par largeur de transect et par site	1 jour pour FAST et 4 jours pour TVW	
Long terme	Activité 5 : Après avoir testé le biais entre les observateurs, planifier les suivis par recensement visuel dans le réseau d'AMPs	TVW et FAST	2 ou 3 sites dans chaque zone, profondeur entre 10 et 20 mètres	Scientifiques, gestionnaires, volontaires	Chaque année	3 réplikat par largeur de transect et par site	-	

Echelle spatiale plus large

Objectif 2 : Le deuxième objectif de la stratégie de suivi proposée est d'évaluer les activités de pêche côtière dans les AMPs.

Comme les données sur la pêche côtière ne sont pas disponibles dans toutes les AMPs, à court terme, trois activités semblent nécessaires. Tout d'abord, le suivi de la fréquentation avec des patrouilles en bateau et avec méthode de suivi par photographie autonome est à mettre en place aussi bien dans des zones protégées et pêchées (comme proposé pour l'archipel de Zembra). Cette dernière méthode pourrait être très utile pour contrôler le braconnage, ce qui est très probable dans une AMP (Bergseth *et al.*, 2017). Deuxièmement, en utilisant les résultats de la première activité, il sera possible de définir les acteurs de la pêche côtière, ce qui est une étape très importante. Les usagers de pêche côtière sont à définir et à considérer pour la planification et la gestion. En se basant sur nos résultats, cette étape a permis de montrer que cette catégorie est la plus impactante et la plus difficile à maîtriser. La troisième activité urgente consiste à surveiller les débarquements pour toutes les catégories de pêche dans les futures AMPs. Il est essentiel que les données collectées contiennent un minimum d'informations, y compris une identification précise des espèces et de leurs tailles, ce qui n'est pas actuellement inclus dans les données officielles des arrondissements de la pêche. Cette information est d'une grande pertinence pour évaluer les effets des AMPs (Di Franco *et al.*, 2016).

Au cours de notre travail, nous avons débuté une approche participative avec les pêcheurs artisanaux et les pêcheurs récréatifs pour aider à surveiller les débarquements. Sur le moyen et le long terme, cela devrait se poursuivre avec la méthode de pêche expérimentale et l'organisation de réunions avec les pêcheurs. Le réseautage avec des personnes ressources les plus concernées par la création et le fonctionnement des AMPs peut contribuer à instaurer la co-gestion dans les AMPs tunisiennes. Le suivi des activités de pêche peut être mis en œuvre à grande échelle en travaillant avec les pêcheurs de manière pratique, en participant à leur activité de pêche, en demandant leur savoir-faire local et en sollicitant leur contribution dans le suivi scientifique. Cela constitue un potentiel à explorer et à consolider au fil des années. D'autres expériences méditerranéennes (Nueva Tabarka) montrent que la confrontation avec les pêcheurs pourrait être inévitable (Bergseth *et al.*, 2017). Mais il s'agit de réduire cet impact de confrontation sur la création et le fonctionnement des AMPs grâce à la participation de pêcheurs « clés ».

L'utilisation des mêmes méthodes pour toutes les futures AMPs permettra l'évaluation de la connectivité d'une AMP à une autre, en réduisant les biais liés aux différences entre méthodes d'échantillonnage (Calò *et al.*, 2013). La question de l'établissement d'un réseau d'AMPs le long des côtes tunisiennes est posée depuis 2000 par le gouvernement tunisien. Cependant, pour assurer l'efficacité de ce réseau, chaque AMP doit être efficace et performante individuellement, avec le suivi des variations spatio-temporelles des assemblages de poissons et l'amélioration des pêches (Roff, 2014). Les mêmes modèles devraient être mesurés au sein du réseau pour tester si le réseau d'AMPs fonctionne ou s'il s'agit seulement d'un set d'AMPs non connectées (Roff, 2014).

Objectif 2: évaluer les activités de pêche côtière dans les AMPs tunisiennes chaque année

	Activités	Méthodes	Sites	Qui	Fréquence	Outils nécessaires	
Court terme	Activité 1 : suivi de la fréquentation	Patrouille, photo pour la surveillance	Zones protégées et non protégées	Scientifiques et gestionnaires d'AMPs	Deux semaines par saison ou continuellement	Bateau ou caméra indépendante	Echantillonnage à petite échelle: une ou quelques AMPs
	Activité 2 : définir les acteurs de pêche côtière	Questionnaire	Zones protégées et non protégées	Scientifiques, gestionnaires et pêcheurs volontaires	Deux semaines par saison	Bateau	
	Activité 3 : suivi des débarquements pour chaque activité de pêche (y compris la taille des captures)	Questionnaire ou photo avec échelle de grandeur	Zones protégées et non protégées	Scientifiques, gestionnaires et pêcheurs volontaires	Deux semaines par saison	Avec ou sans bateau	
Moyen terme	Activité 4 : suivi des captures et renforcement de la communication avec les pêcheurs artisanaux	Pêche expérimentale	3 sites pêchés et 3 sites à la limite de la zone protégée	Scientifiques et gestionnaires	Deux fois par an, 3 répliqués par site	Balance de précision, ichthyomètre	Echelle spatiale plus large
Long terme	Activité 5 : travailler en réseau avec les pêcheurs pour le suivi des captures et les espèces invasives	Organisation de réunions avec les pêcheurs "clés" et autres	Toutes les AMPs du réseau	Scientifiques, gestionnaires, experts en communication et modérateurs	Une fois par an	Stratégie de communication	

Perspectives

❖ Dans l'attente d'un statut légal d'AMPs, protéger autrement ?

Les processus de création de AMPs sont très lents ; depuis l'an 2000 des efforts ont été faits dans cette direction. La loi n'a été décrétée que 9 ans plus tard. En outre, il existe de nombreuses étapes et conditions à remplir. Le problème est qu'il n'est pas possible de commencer à protéger sans fondement juridique. Toutefois, en ce qui concerne l'urgence de la protection nécessaire dans les lieux étudiés, une solution rapide peut être de commencer à protéger les futures zones de non-prise, en tant que petites AMPs qui peuvent également être efficaces pour les espèces de poissons (PISCO & UNS, 2016). Protéger les zones les plus petites semble être plus faisable et pratique, plus facile à contrôler et plus simple pour évaluer leur efficacité. La promulgation de décrets ministériels peut prendre beaucoup moins de temps que d'attendre la loi.

❖ Quantifier l'influence de la complexité paysagère sur les peuplements de poissons ?

A partir des différences significatives détectées au niveau de la structure des assemblages non liée à la protection, d'autres facteurs peuvent être à l'origine de ces différences, notamment la complexité de l'habitat ou les variations du paysage marin. Les variations de la complexité du paysage marin (en fonction des paramètres du modèle spatial structurel du paysage marin) pourraient créer des conditions optimales pour divers assemblages de poissons (Staveley *et al.*, 2016). L'hétérogénéité du paysage marin est reconnue comme un moteur central de nombreux processus écologiques (Walding *et al.*, 2011). Les études appliquant des approches spatiales marines pour expliquer la variabilité de l'assemblage de poissons dans les systèmes marins tropicaux (Darling *et al.*, 2017) et à froid (Staveley *et al.*, 2016) indiquent que la structure du paysage marin joue probablement un rôle important dans la détermination de la composition, de l'abondance et des espèces de la communauté de poissons (Staveley *et al.*, 2016).

Dans les zones marines protégées (AMPs), l'effet réserve sur les assemblages de poissons a été démontré dans de nombreuses AMPs bien gérées (Guidetti *et al.*, 2014). Cependant, l'effet réserve devrait être distingué des effets d'autres facteurs tels que les facteurs physico-chimiques

et l'hétérogénéité de l'habitat marin, ce qui peut masquer notre capacité à discerner les effets réserve (Huntington *et al.*, 2010). La question de la variabilité des structures d'assemblages de poissons sous protection ou sous la complexité du paysage marin a été posée il y a plusieurs années. Elle souligne l'importance relative de la structure de l'habitat, considérée comme un ensemble d'éléments biologiques et physiques du paysage marins disposés hiérarchiquement dans l'espace à plusieurs échelles, conduisant à la variabilité naturelle. La caractérisation de l'hétérogénéité spatiale par rapport aux AMPs méditerranéennes et la quantification des relations entre les espèces de poissons et leurs habitats sont essentielles pour expliquer les variations dans les modèles et les métriques de l'assemblage de poissons (García-Charton *et al.*, 2000). Ainsi, pour les emplacements tunisiens étudiés, la quantification de l'intégrité du paysage marin (Thorin *et al.*, 2014) ou la complexité du paysage marin peut être une étape antérieure. Par exemple, dans les îles Kuriat et Tabarka, les sites BIO19 et BIO11, et TU se caractérisent par la présence de grandes cavités (Supplementary Material III.3). Dans Cap Negro Cap Serrat, il n'y a pas de tels sites. Nous croyons que cette différence peut entraîner des différences naturelles entre ces sites qui seront des zones de non-prise, et les autres, les zones à usages multiples et les zones non protégées. C'est pourquoi, une plus grande quantification utilisant des méthodes exhaustives devrait être appliquée dans les mêmes sites pour explorer la complexité paysagère et celle de l'habitat en fonction de l'abondance, la biomasse et la protection.

❖ Tester la performance des STV pour l'application de méthodes standard de comptage de poissons, les transects ?

La science participative dans le cadre de ce travail est proposée comme un moyen efficace pour collecter des données utiles sur les peuplements de poissons dans les futures AMPs d'études. La méthode utilisée par les STV jusqu'ici est la méthode FAST qui fournit un minimum d'informations de présence absence avec indication de la classe de taille. Au vu du potentiel d'implication des plongeurs volontaires impliqués dans les suivis de 84 AMPs dans le monde (Edgar *et al.*, 2014), l'apprentissage et l'application de méthodes plus exhaustives serait intéressant à tester.

- ❖ Déterminer l'impact de la pêche côtière sur les assemblages de poissons : utilité du couple données empiriques/ modélisation ?

Jusqu'ici, dans les futures AMPs étudiées, la définition de la situation actuelle et des dimensions écologiques et socio-économiques des activités de pêche côtière, a été explorée. Par ailleurs, les impacts des différentes catégories de pêche sur les assemblages de poissons (e.g. espèces et catégories les plus impactées) n'ont pas été explorés auparavant. Pour cela, la modélisation exploitant les données empiriques (Pelletier *et al.*, 2008) pourrait renseigner sur des scénarios d'exploitation et de régulation des activités de pêche côtière. Ce serait bien utile pour les gestionnaires des futures AMPs (Prato *et al.*, 2016), qui pourraient même décider de communiquer sur les scénarios auprès des pêcheurs.

- ❖ Définir de plus près la relation entre la pêche illégale et les facteurs socio-économiques dans des zones « pilotes » en Tunisie et dans d'autres pays du sud et de l'est de la Méditerranée ?

Il a été démontré que la pêche illégale dans les pays en développement est favorisée par des conditions socio-économiques difficiles (Drammeh *et al.*, 2012 ; FAO, 2016). Toutefois, ce point n'a pas été exploré aux échelles plus locales, pour identifier la relation directe ou indirecte de causalité entre les facteurs socio-économiques et l'incidence de la pêche illégale. Cela est loin d'être facile à déterminer. Par contre, étant donné la forte interdisciplinarité dans les AMPs, il serait utile d'essayer d'explorer lesdites relations et leurs relations au sein des AMPs.

Conclusion

This PhD aimed at adapting, testing and suggesting a monitoring strategy of fish and fisheries in future MPAs in Tunisia. In the suggested methodology (of the 5 applied methods and their outputs), reliability, feasibility, concreteness, match with MPAs objectives, participatory approach were taken into account. The originality of this work remains in the following results :

- ❖ First scientific assessment of fish assemblages metrics by UVC means in Tunisia and « before impact » data for future MPAs, which can grant a reliable assessment of the effect of protection in the future.
- ❖ First assessment of compliance between a standard UVC method and an easy-to-use one (FAST method, after adapting it for Tunisia), allowing testing the FAST method with scientifically trained volunteers (STV) who have the potential to contribute actively in collecting fish assemblage data.
- ❖ Demonstration of the improvement and the effectiveness of STV in size estimation of fish underwater, after three training campaigns, using adequate material.
- ❖ First assessment of illegal fishing as a common coastal fishing practice, its percentages, catch, and its competition with CSS and recreational fishing.
- ❖ The proposal of the photo-surveillance method.

However, this work was confronted to some limits :

- ❖ An accurate assessment of the factors that could affect fish assemblage variability in the studied areas.
- ❖ Testing the ability of STV to apply a standard UVC method, which needs a long training.
- ❖ There were no coastal fishing surveys in Cap Negro Sidi Mechreg during 2014, which limited coastal fishing seasonality assessment to only two future MPAs. Further assessment of coastal fishing catch during 2016 is missing also, this could trigger more discussions about the impact of coastal fishing on fish assemblages.

- ❖ A frequentation survey to assess an approximate number of recreational fishers in future MPAs, which could allow estimations of the total recreational catch.
- ❖ More accurate assesement of CSS catch using experimental fishing method.
- ❖ More results using photo-surveillance method.

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Appendices

Appendix 1: Tables of criteria to choose Target fish to monitor using FAST

	poissons Tunisie/ critères	zone de 0 à 30 m	endémisme	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherchée par la pêche pro et amateur ou l'un ou	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
N°	Espèces/ Scores	0: non, 1: oui	0: non, 1: oui	facile à identifier : 2 genre facile à identifier: 1 pas facile à identifier : 0	0 : abondant 1 : moins abondant 2 : rare	strictement herbivore ou carnivore : 1 sinon 0	0: non, 1 : oui	0 : de 1 à 7 1: de 8 à 15 et 2 de 16 à 50	0: non 1 : Oui	2: plusieurs types de pêche 1: un seul type de pêche 0 : peu ou pas recherchées	0: pas vulnérable 1: vulnérable 2: en danger	0: non, 1 : oui	0: non, 1: oui	S	je prend un seuil de 10 comme min (endémique(1), facile à identifier(2),moins abondante (1), strictement her ou car (1),haut niveau troph (0), long de 8 à 15 (1), chgmt sex (1), recherchées par un type de pêche (1), vuln (1), et sp habitat (1)
1	<i>Anguilla anguilla</i>	1	0	2	0	0	0	2	1	0	2	0	0	7	non retenue
2	<i>Acipenser sturio</i>	1	0	2	2	1	0	1	0	1	1	0	0	9	non retenue
3	<i>Antonogadus megalokynodon</i>	0	1	1	1	0	0	0	0	0	0	0	0	0	non retenue
4	<i>Aphanius fasciatus</i>	1	1	1	2	0	0	0	0	0	1	0	0	5	non retenue
5	<i>Apogon imberbis</i>	1	0	2	0	1	0	0	1	0	0	1	0	5	non retenue
6	<i>Argyrosomus regius</i>	0	0	1	1	1	0	1	1	1	0	0	0	0	non retenue
7	<i>Ariosoma balearicum</i>	1	0	0	1	1	0	1	1	0	0	0	0	4	non retenue
8	<i>Aspitrigla obscura</i>	0	0	1	1	0	0	0	1	1	0	0	0	0	non retenue
9	<i>Atherina spp</i>	1	0	1	0	0	0	0	0	1	0	1	0	4	non retenue

	poissons Tunisie/ critères	zone de 0 à 30 m	endémisme	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherchée par la pêche pro et amateur ou l'un ou l'autre	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes et les adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
11	<i>Belone belone</i>	1	0	1	0	1	1	1	0	1	0	1	0	8	non retenue
12	<i>Blennius ocellaris</i>	1	0	2	1	0	0	0	0	0	0	0	0	3	non retenue
13	<i>Boops boops</i>	1	0	2	0	0	0	0	1	1	0	1	0	6	non retenue
14	<i>Bothus podas</i>	1	0	1	0	1	0	0	0	1	0	1	0	5	non retenue
15	<i>Brama brama</i>	1	0	1	1	1	0	1	0	1	0	0	0	6	non retenue
16	<i>Callanthias ruber</i>	0											0	0	non retenue
17	<i>Caranx crysos</i>	1	0	2	0	1	0	1	0	1	0	0	0	6	non retenue
18	<i>Cepola macrophthalmia</i>	1	0	2	1	0	0	1	0	0	0	0	0	4	non retenue
19	<i>Channa asiatica</i>	0											0	0	non retenue
20	<i>Glossanodon leiglossus</i>	1	0	1	1	0	0	1	0	0	0	0	0	3	non retenue
21	<i>Chromis chromis</i>	1	0	2	0	0	0	0	0	0	0	0	0	2	non retenue
22	<i>Citharus linguatula</i>	1	0	0	1	0	0	1	0	0	0	1	0	3	non retenue
23	<i>Conger conger</i>	1	0	2	1	1	1	2	1	1	0	1	0	12	Conger conger
24	<i>Coris julis</i>	1	0	2	1	1	0	0	1	0	0	0	0	5	non retenue
25	<i>Coryphaena hippurus</i>	1	0	2	0	1	1	0	0	1	0	0	0	7	non retenue

	poissons Tunisie/ critères	zone de 0 à 30 m	endémisme	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherchée par la pêche pro et amateur ou l'un ou l'autre	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes et les adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
26	<i>Dactylopterus volitans</i>	1	0	1	1	1	0	0	1	1	0	1	0	7	non retenue
27	<i>Dasyatis spp</i>	1	0	1	1	1	0	2	0	0	0	0	0	5	non retenue
28	<i>Dasyatis pastinaca</i>	1	0	2	2	1	1	1	0	1	1	0	0	11	<i>Dasyatis pastinaca</i>
29	<i>Dentex dentex</i>	1	0	2	1	1	1	2	0	2	1	0	0	13	<i>Dentex dentex</i>
30	<i>Dentex gibbosus</i>	1	0	1	1	1	1	1	1	1	0	0	0	9	non retenue
31	<i>Dentex maroccanus</i>	1	0	1	1	1	1	1	0	1	0	0	0	8	non retenue
32	<i>Diaphus metopoclampus</i>	0											0	0	non retenue
33	<i>Dicentrarchus labrax</i>	1	0	2	2	1	1	2	0	2	1	0	0	14	<i>Dicentrarchus labrax</i>
34	<i>Dicentrarchus punctatus</i>	0											0	0	non retenue
35	<i>Diplodus annularis</i>	1	0	2	1	0	0	1	0	2	1	1	0	10	<i>Diplodus annularis</i>
36	<i>Diplodus cervinus</i>	1	0	2	2	1	0	1	0	2	1	1	0	12	<i>Diplodus cervinus</i>
37	<i>Diplodus puntazzo</i>	1	0	2	1	0	0	1	0	2	1	1	0	10	<i>Diplodus puntazzo</i>

	poissons Tunisie/ critères	zone de 0 à 30 m	endémisme	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherche par la pêche pro et amateur ou l'un ou l'autre	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes et les adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
38	<i>Diplodus sargus</i>	1	0	2	1	0	0	1	0	2	1	1	0	10	<i>Diplodus sargus</i>
39	<i>Diplodus vulgaris</i>	1	0	2	1	0	0	1	0	2	1	1	0	10	<i>Diplodus vulgaris</i>
40	<i>Epinephelus spp</i>	0											0	0	non retenue
41	<i>Epinephelus costae</i>	1	0	2	2	1	1	2	1	2	1	1	0	16	<i>Epinephelus costae</i>
42	<i>Epinephelus marginatus</i>	1	0	2	2	1	1	2	1	2	2	1	0	17	<i>Epinephelus marginatus</i>
43	<i>Fistularia comersonii</i>	1	0	2	1	1	1	1	0	0	0	0	1	9	non retenue
44	<i>Gnathophis mystax</i>	0											0	0	non retenue
45	<i>Gymnura altavela</i>	1	0	2	1	0	0	1	0	0	1	0	0	5	non retenue
46	<i>Helicolenus dactylopterus</i>	0											0	0	non retenue
47	<i>Heptanchias perlo</i>	1	0	1	1	1	1	2	0	0	1	0	0	8	non retenue
48	<i>Hirundichthys rondeleti</i>	0											0	0	non retenue
49	<i>Hyporhamphus picarti</i>	0											0	0	non retenue
50	<i>Hippocampus spp</i>	1	1	1	2	1	0	0	0	1	2	0	0	9	non retenue
51	<i>Lobotes surinamensis</i>	0											0	0	non retenue

	poissons Tunisie/ critères	zone de 0 à 30 m	end émise	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherchée par la pêche pro et amateur ou l'un ou l'autre	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes et les adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
68	<i>Mullus surmuletus</i>	1	0	1	1	0	0	1	0	1	0	1	0	6	non retenue
69	<i>Muraena helena</i>	1	0	2	1	1	1	1	0	1	0	1	0	10	<i>Muraena helena</i>
70	<i>Mustelus asterias</i>	0											0	0	non retenue
71	<i>Mustelus mustelus</i>	1	0	1	1	0	0	1	0	0	1	0	0	4	non retenue
72	<i>Mustelus punctulatus</i>	0											0	0	non retenue
73	<i>Mycteroperca rubra</i>	1	0	1	2	1	1	2	1	2	1	1	0	15	<i>Mycteroperca rubra</i>
74	<i>Myliobatis aquila</i>	1	1	2	2	1	0	2	0	0	1	1	0	10	<i>Myliobatis aquila</i>
75	<i>Nezumia sclerorhynchus</i>	0											0	0	non retenue
76	<i>Oblada melanura</i>	1	0	2	0	0	0	1	1	0	0	0	0	4	non retenue
77	<i>Pagellus acarne</i>	0	0	1	0	0	0	0	1	1	0	0	0	0	non retenue
78	<i>Pagellus bogaraveo</i>	0	0	1	1	0	0	1	1	1	0	0	0	0	non retenue
79	<i>Pagellus erythrinus</i>	0	0	1	0	0	0	1	1	1	0	0	0	0	non retenue
80	<i>Pagrus coeruleostictus</i>	0											0	0	non retenue
81	<i>Pagrus pagrus</i>	1	0	2	2	1	0	1	1	2	2	0	0	13	<i>Pagrus pagrus</i>

	poissons Tunisie/ critères	zone de 0 à 30 m	end émise	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherchée par la pêche pro et amateur ou l'un ou l'autre	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes et les adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
82	<i>Parablennius rouxi</i>	1	1	2	1	0	0	0	0	0	0	0	0	4	non retenue
83	<i>Parexocoetus mento</i>	1	0	2	1	0	0	0	0	0	0	0	0	3	non retenue
84	<i>Pempheris vanicolensis</i>	1	0	2	1	1	0	0	0	0	0	1	1	7	non retenue
85	<i>Peristedion cataphractum</i>	0											0	0	non retenue
86	<i>Phycis phycis</i>	1	1	2	2	1	0	2	0	2	1	1	0	14	Phycis phycis
87	<i>Polyprion americanus</i>	0											0	0	non retenue
88	<i>Pomadasys incisus</i>	1	0	0	1	1	0	0	0	1	0	0	1	6	non retenue
89	<i>Pomatomus saltatrix</i>	1	0	1	1	1	1	1	0	2	0	0	0	10	Pomatomus saltatrix
90	<i>Priacanthus hamrur</i>	1	0	1	1	0	0	0	1	0	0	0	0	3	non retenue
91	<i>Pteromylaeus bovinus</i>	1	0	1	1	1	0	2	0	0	0	0	0	5	non retenue
92	<i>Raja alba</i>	0											0	0	non retenue
93	<i>Raja asterias</i>	0	1	1	1	0	0	1	1	0	1	0	0	0	non retenue
94	<i>Raja clavata</i>	1	0	1	1	0	0	1	1	0	1	0	0	5	non retenue
95	<i>Raja melitensis</i>	0											0	0	non retenue

	poissons Tunisie/ critères	zone de 0 à 30 m	endémisme	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherchée par la pêche pro et amateur ou l'un ou l'autre	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes et les adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
96	<i>Salaria basiliscus</i>	1	1	1	1	0	0	0	1	0	0	0	0	4	non retenue
97	<i>Sardina sp</i>	1	1	1	0	0	0	1	0	1	0	0	0	5	non retenue
98	<i>Sarpa salpa</i>	1	0	2	1	1	0	1	1	1	1	1	0	10	<i>Sarpa salpa</i>
99	<i>Sciaena umbra</i>	1	1	2	2	1	0	2	0	2	1	0	0	13	<i>Sciaena umbra</i>
100	<i>Scomber sp</i>	1	0	1	0	0	0	2	0	1	0	0	0	5	non retenue
101	<i>Scophthalmus rhombus</i>	1	0	0	0	1	0	0	0	0	0	1	0	2	non retenue
102	<i>Scorpaena elongata</i>	0											0	0	non retenue
103	<i>Scorpaena notata</i>	1	1	1	1	1	0	1	0	1	0	0	0	7	non retenue
104	<i>Scorpaena</i>	1	0	1	1	1	0	1	0	1	0	0	0	6	non retenue
105	<i>Scorpaena scrofa</i>	1	0	2	2	1	1	1	0	2	1	1	0	14	<i>Scorpaena scrofa</i>
106	<i>Scyliorhinus canicula</i>	0											0	0	non retenue
107	<i>Scyliorhinus stellaris</i>	1	1	1	2	1	0	2	0	0	1	0	0	8	non retenue
108	<i>Seriola carpenteri</i>	1	0	0	0	1	1	1	0	2	0	1	0	9	non retenue
109	<i>Seriola dumerilii</i>	1	0	2	1	1	1	1	0	2	0	1	0	12	<i>Seriola dumerilii</i>
110	<i>Seriola fasciata</i>	0											0	0	non retenue

	poissons Tunisie/ critères	zone de 0 à 30 m	end émise	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherchée par la pêche pro et amateur ou l'un ou l'autre	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes et les adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
111	<i>Serranus cabrilla</i>	1	0	2	1	1	0,5	1	1	2	0	0	0	11	<i>Serranus cabrilla</i>
112	<i>Serranus hepatus</i>	0	1	1	1	1	0	1	1	0	0	0	0	0	non retenue
113	<i>Serranus scriba</i>	1	1	2	0	1	0,5	1	1	2	0	0	0	11	<i>Serranus scriba</i>
114	<i>Siganus sp</i>	1	0	1	1	1	0	1	0	1	0	0	1	8	non retenue
115	<i>Solea impar</i>	1	0	1	1	0	0	2	1	0	0	1	0	6	non retenue
116	<i>Solea senegalensis</i>	1	0	1	0	1	0	2	1	1	0	1	0	8	non retenue
117	<i>Solea solea</i>	0	0	1	1	1	0	1	1	1	0	1	0	0	non retenue
118	<i>Sparisoma cretense</i>	1	0	2	1	0	0	1	1	0	0	0	0	5	non retenue
119	<i>Sparus aurata</i>	1	0	2	1	0	0	1	1	2	0	0	0	9	non retenue
120	<i>Sphoeroides cutaneus</i>	0											0	0	non retenue
121	<i>Spheroides pachygaster</i>	0	0										0	0	non retenue
122	<i>Sphyraena SP</i>	1	0	1	1	1	1	1	0	2	0	1	0	11	<i>Sphyraena SP</i>
123	<i>Spicara SP</i>	1	0	1	0	0	0	1	1	1	0	1	0	6	non retenue
124	<i>Spondyliosoma cantharus</i>	1	0	2	1	1	0	2	0	2	0	0	0	10	<i>Spondyliosoma cantharus</i>
125	<i>Squatina oculata</i>	0											0	0	non retenue

	poissons Tunisie/ critères	zone de 0 à 30 m	endémisme	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherchée par la pêche pro et amateur ou l'un ou l'autre	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes et les adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
126	<i>Stephanolepis diaspro</i>	1	0	1	0	0	0	0	0	0	0	0	0	1	non retenue
127	<i>Stomias boa stromateus</i>	0	0										0	0	non retenue
128	<i>fiatola</i>	1	0	1	1	1	0	2	0	1	0	0	0	7	non retenue
129	<i>Symphodus cinereus</i>	1	0	1	1	0	0	0	1	0	0	1	0	4	non retenue
130	<i>Symphodus doderleini</i>	1	1	1	1	0	0	1	1	0	0	0	0	5	non retenue
131	<i>Symphodus mediterraneus</i>	1	1	1	0	0	0	0	1	0	0	0	0	3	non retenue
132	<i>Symphodus melanocercus</i>	1	1	1	0	0	0	1	1	0	0	0	0	4	non retenue
133	<i>Symphodus ocellatus</i>	1	1	1	0	0	0	1	1	0	0	0	0	4	non retenue
134	<i>Symphodus roissali</i>	1	1	1	0	0	0	0	1	0	0	0	0	3	non retenue
135	<i>Symphodus rostratus</i>	1	1	1	0	0	0	0	1	0	0	0	0	3	non retenue
136	<i>Symphodus tinca</i>	1	1	1	0	0	0	1	1	1	0	0	0	6	non retenue
137	<i>Synchiropus phaeton</i>	0											0	0	non retenue
138	<i>Thalassoma pavo</i>	1	0	2	0	0	0	1	1	0	0	0	0	4	non retenue
139	<i>torpedo marmorata</i>	1	0	1	1	1	0	1	0	0	0	0	0	4	non retenue

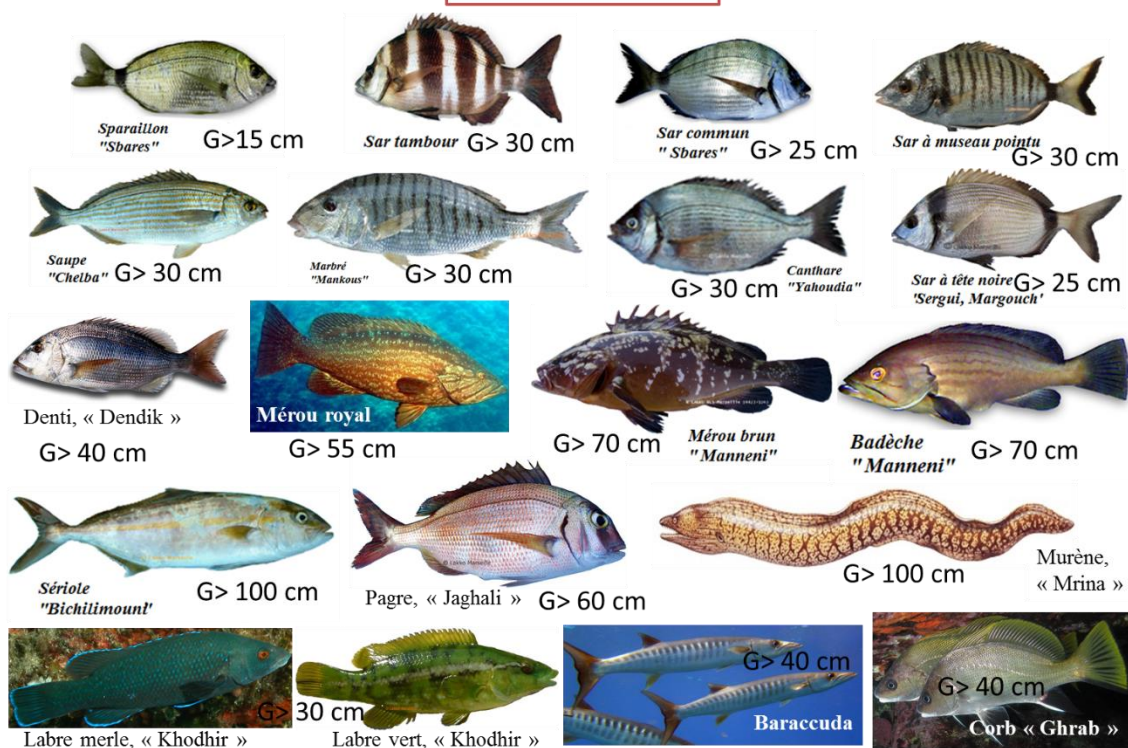
	poissons Tunisie/ critères	zone de 0 à 30 m	endémisme	identification	estimation de l'abondance en Tunisie	régime alimentaire	Prédateur de haut niveau trophique	longévité an	changement de sexe au cours de la vie	recherche par la pêche pro et amateur ou l'un ou l'autre	vulnérabilité	Spécificité vis-à-vis de l'habitat (pour les sub-adultes et les adultes)	Lessepsien ou herculéen en expansion	S	Commentaires
140	<i>Torpedo torpedo</i>	1	0	1	0	1	0	1	0	0	0	0	0	3	non retenue
142	<i>Trachurus sp</i>	0	0	1	0	0	0	0	0	1	0	0	0	0	non retenue
143	<i>Trachinotus ovatus</i>	0											0	0	non retenue
144	<i>Trigla lucerna</i>	1	1	1	0	1	0	1	0	1	0	0	0	6	non retenue
145	<i>Trigloporus lastoviza</i>	1	1	1	0	1	0	1	0	1	0	0	0	6	non retenue
146	<i>Tripterygion delaisi</i>	1	0	1	1	0	0	0	0	0	0	0	0	2	non retenue
147	<i>Tripterygion melanurum</i>	1	1	1	1	0	0	0	0	0	0	0	0	3	non retenue
148	<i>Umbrina cirrosa</i>	1	0	1	1	1	0	1	0	2	0	0	0	8	non retenue
149	<i>Uranoscopus scaber</i>	1	0	0	1	1	0	1	0	0	0	1	0	4	non retenue

Appendix 2: FAST board for volunteer divers

Poissons FAST Tunisie

LISTE PRINCIPALE

Emna BENLAMINE, 2014

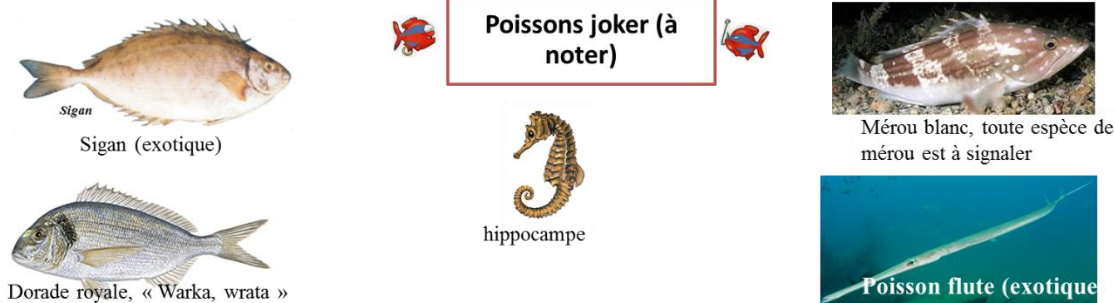


G > 25 cm

LISTE PRINCIPALE



Poissons joker (à noter)



Pêche à la ligne				
Ce questionnaire est anonyme. Il ne revêt aucun caractère obligatoire				
N°.....		Enquêteur.....		
date.....		Zone		
Quand pêchez vous ?				
Au cours de l'année:	toute l'année	été	hiver	vacances
	weekend	semaine	indifférent	
Au cours de la journée	matin	après midi	Nuit	
Durée de la pêche.....				
heure de début?.....heure de fin.....				
fréquence des sorties par semaine ou par mois			
Type d'engins				
	ligne avec canne	ligne à la main	autres.....	
Nombre de cannes ou de lignes				
Nombre d'hameçons par canne ou ligne				
Taille des hameçons				
Types d'appât.....				
Quels sont les Poissons que vous capturez?				
	poisson	taille approximative		
Volume de poissons capturés à chaque sortie en moyenne			
Vente de poissons			
Avez vous noté la présence d'espèces nouvelles ? Depuis quand?				
.....				
Données personnelles				
année de naissance.....				
Profession.....				
Lieu de résidence.....				

