EFFICIENCY OF « TABU » AREAS IN VANUATU (EFITAV 2 PROJET)

IRD Institut de recherche pour le développement

GOUVERNEMENT DE LA NOUVELLE CALÉDONIE

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FISHERIES DEPARTMENT OF VANUATU

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SUMMARY

In response to the priorities expressed by the Vanuatu Fisheries Department, the EFITAV program 2011 - 2014 ("Ecological efficiency of tabu areas in Vanuatu") focuses on the strengthening of marine resource management initiatives, through the study of the effect of "tabu areas" (small reserves managed by local communities) on reef resources.

Second and final part of EFITAV program, this study focuses on **the definition of relevant management scales for the main resources of fish and reef invertebrates**, through the study of their movements between or within tabu areas of the zone North Efate island.

PART 1. HOME RANGE ESTIMATION FOR TROCHUS NILOTICUS INSIDE THE TABU AREAS OF TAKARA AND MANGALILIU

The movements of trochus were studied using various tagging techniques ("classic" tags, accelerometer sensors) in the tabu areas of Mangaliliu and Takara (Efate, Vanuatu). The main results are:

- This study confirms the sedentary and nocturnal behavior of the species: individuals exhibit locomotor activity restricted to night-time only, with a complete cessation of movement during the day. This feature is more pronounced for older, larger individuals than for young specimens;

- In normal conditions (favorable habitat), the home range (area in which individuals commonly evolve) appears particularly restricted. For most individuals, we observed strong site fidelity, trochus staying within a reef area of a few tens of meters radius. If the habitat is not perceived as favorable, however, significantly larger displacements can be observed: up to ten meters in one night.

In terms of management, these results lead to the following conclusions:

- Despite their limited reef area (i.e. a few hundred meters linear), the vast majority of tabu areas most likely have sufficient size to provide effective protection to adult trochus;

- The ability of tabu areas to efficiently protect (aggregate) trochus adult biomass is highly dependent upon on the presence of favorable, specific benthic habitats;

- These ecological characteristics offer very interesting prospects for reseeding operations (rebuild populations in depleted reefs).

PART 2. EFFECTS OF THE MOVEMENTS OF FIVE REEF FINFISH SPECIES ON THE EFFECTIVENESS OF TABU AREAS

The movements of 5 fish species (*Naso unicornis, Scarus altipinnis, Scarus ocellatus, Cetoscarus microrhinos and Scarus oviceps*) have been studied within and out of the tabu areas of Takara and Worasiviu (Efate, Vanuatu). The main results are:

- When there was sufficient data (for about 50% of the fish), home range was estimated between 100 m and 2300 m, although some fish have made much longer trips over several km. Three distinct types of behaviors were highlighted: sedentary fish with a small home range (100-700 m), mobile fish with large home ranges (1100-2300 m), and an intermediate category;

- The estimated parameters (fish length, linear extent of KUD50 and KUD95 areas, frequency and duration of excursions) showed no significant differences between species, suggesting that fish behaviors were broadly similar among the five species;

- The observations suggest that suggests that larger fish tend to use larger reef areas than smaller fish, however this relationship was not invariable.

In terms of management, these results lead to the following conclusions:

- If one considers that the protection of adult fish is effective when its home range is included in the protected area, it must be both large enough and located on suitable habitats;

- We recommend to protect reef areas extending at least over 1000 m to 2000 m (linear) in appropriate habitats in order to take into account the wide variety of reef fish behavior, and to provide sufficient protection to most of them, especially the larger ones;

- Small reserves can protect sedentary fish and sometimes big fish as shown in our study. However although this effect may be perceived by communities, our results suggest that this should not mask the fact that this protection would benefit only to a small part of fish resources;

- Our results suggest to design fishing restrictions not only at village level. The inherent limitations of community-based management approaches in Vanuatu islands shall be recognized, particularly in the more populated islands where distances between villages are small. Rather than setting up small reserves that would hardly provide sufficient biomass increase, community efforts could be directed to other management measures to better control fishing pressure. Inter-village management agreements and the implementation of national regulations concerning reef finfish (e.g. mesh sizes of gillnets) are recommended.

PROJECT CONTEXT

On most islands of Vanuatu, the coastal communities are currently facing a marked depletion of their reef resources, in particular commercial and subsistence fish / invertebrate species. Despite a limited population (about 247,000 inhabitants in 2012), the pressure on these resources locally reaches high levels for local (island) consumption, to supply the market in Port Vila or for export. The situation is particularly alarming for reef invertebrates subject to traditional fishing, whose decline has increased over the last decades: stocks of the main harvested molluscs (trochus, green snails, giant clams), echinoderms (sea cucumbers, sea urchins) and crustaceans (lobster, coconut crabs) now show clear signs of overfishing. Similar trends were also observed for reef fish (eg. hunchbacks, parrots, barbs, loaches), although attenuated by higher dispersal capabilities for these species.

In response to the priorities expressed by the Vanuatu Fisheries Department, the EFITAV program focuses on the strengthening of coastal marine resource management initiatives, particularly through the study of the effect of "tabu areas" (small reserves managed by local communities) on reef resources.

The first part of the program EFITAV (1 EFITAV 2011-2012) addressed the ecological capacity of tabu areas to restore and/or sustain the stocks of reef fish and invertebrates. **In this second part (EFITAV 2, 2013-2014), we investigated the relevant management scales for these species, through the study of their movement between or within tabu areas in the northern part of the island of Efate.**

In particular, we addressed the following question: " what is the relevant scale (reef, village, several villages, island) to manage reef resources with optimal efficiency? ".

PART 1. HOME RANGE ESTIMATION FOR TROCHUS NILOTICUS INSIDE THE TABU AREAS OF TAKARA AND MANGALILIU

1.1. OBJECTIVES

In Vanuatu, "tabu areas" are generally very small marine reserves (typically a few hectares to a few tens of hectares of reefs) primarily managed and enforced by the coastal communities. Among other factors, their efficiency in restoring or sustaining small coastal fisheries theoretically depends upon the ratio between their size and the dispersal abilities of the target species: highly mobile species will have a tendency to get out from small reserves more easily; conversely, highly sedentary species would be more effectively protected, even in very small reserves.

In this first part of the study, we investigated the mobility and dispersal abilities of trochus (*Tectus niloticus*), a heavily targeted mollusk whose high value and non-perishable quality make it an attractive source of income for the coastal communities in Vanuatu. Prized for its shell and flesh, this large gastropod (maximum diameter of the shell around 15 cm) is usually considered sedentary. Rather limited movement capabilities (the animal moves by crawling on bedrock) suggest a relatively small home range. If confirmed, these ecological traits could be a decisive advantage for managing adult stocks, in particular if adults appear confined within the spatial boundaries of tabu areas usually encountered in Vanuatu.

1.2. DATA COLLECTION AND ANALYSIS

The movements of trochus were studied using various tagging techniques in two size-contrasted tabu areas, considered representative of situations commonly encountered across the archipelago: the tabu area of Takara (North Efate, reef area 3.3 ha, linear reef extension of 1000 m) and the tabu area of Mangaliliu (West Efate, reef area 25 ha, linear reef extension of 2000 m).

1.2.1 Individual tagging

Figure 1. Trocas marqués

For the tagging survey, 100 specimens (size range 82 – 145 mm) were collected by a team of snorkelers inside each tabu area. Each trochus was tagged using an individual, numbered soft plastic tags of 2 x 1cm screwed to the outer margin of the shell after a 3 mm hole was drilled through each shell lip with a masonry drill bit. Each tag was further secured by an aluminum washer (Fig. 1). On the same day, the tagged specimens were released in their respective tabu areas; snorkelers carefully replaced the trochus under natural shelters (crevices, tabular corals etc.) so as to avoid immediate post-tagging predation.

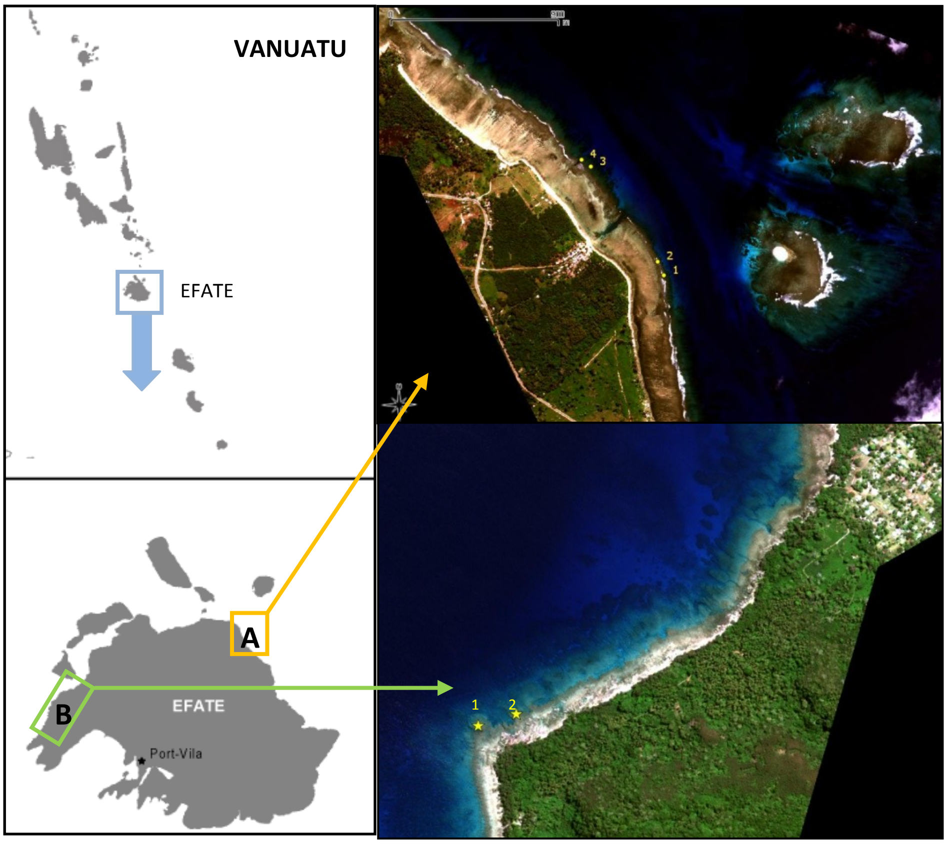

Figure 2. Study zone for the trochus tagging study.
A. Takara tabu area. **B.** Mangaliliu tabu area.

The position of the tagged specimens was periodically assessed after 2, 4 et 9 months in Takara, or every 2 months during 15 months in Mangaliliu. During each survey, the search was conducted by a team of 4 to 6 snorkelers, swimming for 60 to 90 minutes in concentric circles around each release point to locate the tagged specimens. In order to avoid displacing and stressing the animals, all the tagged trochus sighted had their position signaled by a small surface buoy, connected by a short string to a 1kg weight deposited on the substrate right next to the animal. The position of each buoy was then recorded by a snorkeler holding a handheld Garmin GPSMap 60Cx placed in an underwater housing, gently pulling the string so that the buoy was vertical to the tagged specimen.

The spatial analysis of movements was mainly done using a GIS software [especially QGIS, freely downloadable from www.qgis.org/].

1.2.2 Accelerometer study

Figure 3. Trocas equipped with accelerometer sensors

This long-term tagging study was complemented by an analysis of the short-term (i.e. daily) movements and activity rhythms of trochus using accelerometers. In June 2013, eight individuals (4 small trochus of 80-90 mm shell basal diameter, and 4 large trochus, 120-140 mm shell basal diameter) were equipped with accelerometer sensors (Ref. HOBO Pendant-G UA-004-64, Onset Computer Corporation), screwed on the exterior of the shell with steel brackets. These accelerometers weighted 18 g (3 to 18% of the weight of the animal) and were used to measure the acceleration of the animals in the three axes X, Y and Z at a frequency of 0.25 Hz, i.e. a measurement performed every 4 seconds for 24 hours. In the field, the data were then uploaded to a laptop without via a waterproof shuttle system to avoid disturbing the animal (see Figure 3: trochus equipped with sensors and waterproof data acquisition system).

In parallel, the daily horizontal displacements of trochus equipped with these devices were estimated by trilateration (measuring distances from three reference stakes) over a period of 3 days: the position of each individual was obtained using direct underwater visual observations every 90 minutes during the whole night time.

1.3. RESULTS

1.3.1 Individual tagging

Overall, a very significant proportion of the tagged individuals was found in all search campaigns: average recapture rate varies around 56% (Mangaliliu tabu area) and 66% (Takara tabu area). This indicator shows a predictable decrease over time, as individuals further disperse around the release points, thus leading to a decrease in the research effort per unit area. The highest recapture rate is reached during the first research campaigns (72% and 82% to Takara and Mangaliliu, respectively) and gradually decreases to 56% in Takara after 9 months and 37% after 15 months in Mangaliliu (see Figure 4).

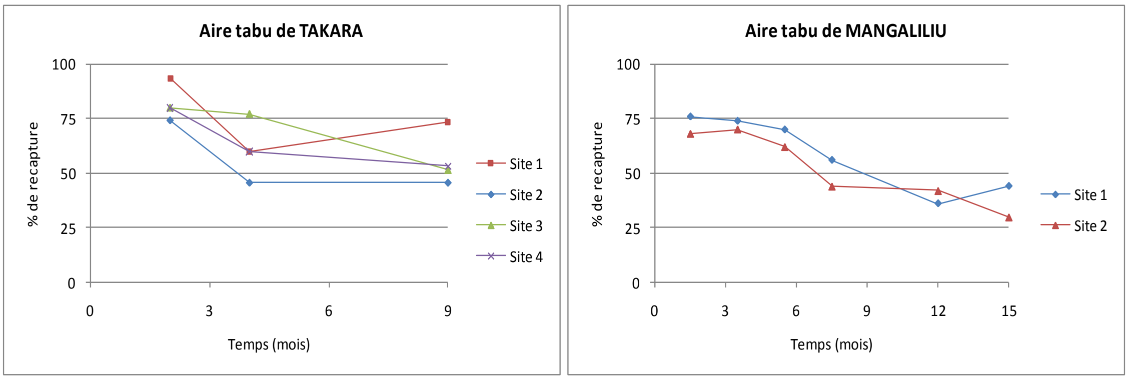

Figure 4. Evolution of the recapture rate for trochus in the Takara and Mangaliliu tabu areas.

It is significant to note that even more than one year after release, the number of tagged individuals found alive in both tabu areas was still high. In Mangaliliu for example, 37 of the 100 tagged specimens were found alive 15 months after their release (22 on site 1, i.e. 44% recapture; 15 of Site 2, i.e. 30% recapture). Similarly, in Takara, 53 of the 100 tagged trochus were found alive after 9 months.

The spatial analysis underlines a very limited dispersal of the tagged trochus on the reefs of the tabu areas studied (Figure 5). The cloud representing the tagged individuals appears circumscribed in a small area of about 40 m radius, regardless of the survey date or the reef considered. In fact, most individuals were found very close to their point of release: **about 90% of the tagged trochus found again during the study were less than 30 meters from the initial releasing point**.

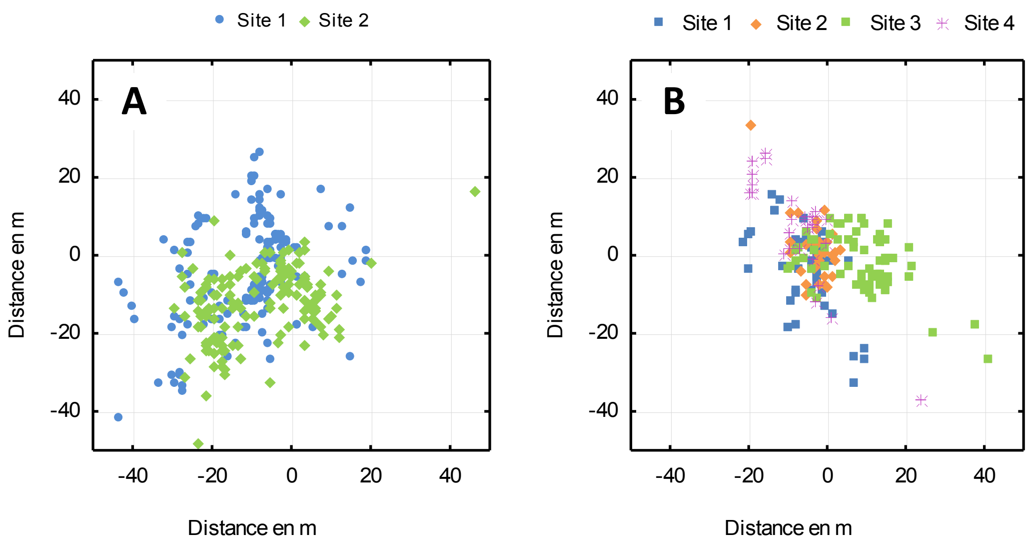

Figure 5. Spatial dispersion of the tagged trochus in the studied areas.
A. Mangaliliu **B.** Takara. Distances (expressed in meters, from the center of the graph) indicate the position of each individual from its initial release position. The temporal search surveys are not distinguished on the graph.

For both tabu areas, the distance to the initial release position increases slightly but statistically significantly over time. It reflects a slow but gradual dispersion of the trochus on the reefs around their release positions, with a distance more pronounced from 12 months on (Figures 6 and 7).

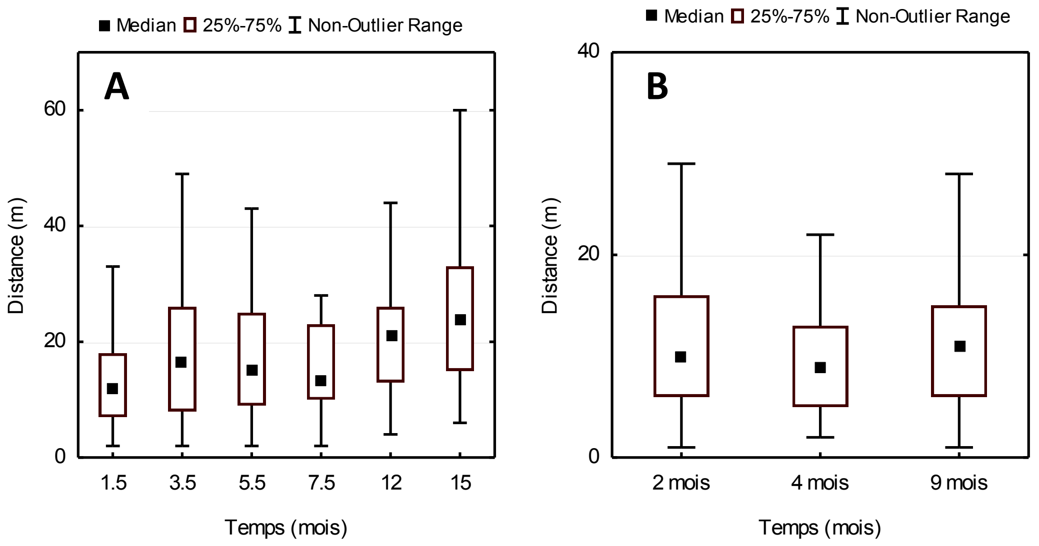

Figure 6. Temporal evolution of the distances travelled by the tagged trochus.
A. Mangaliliu **B.** Takara.

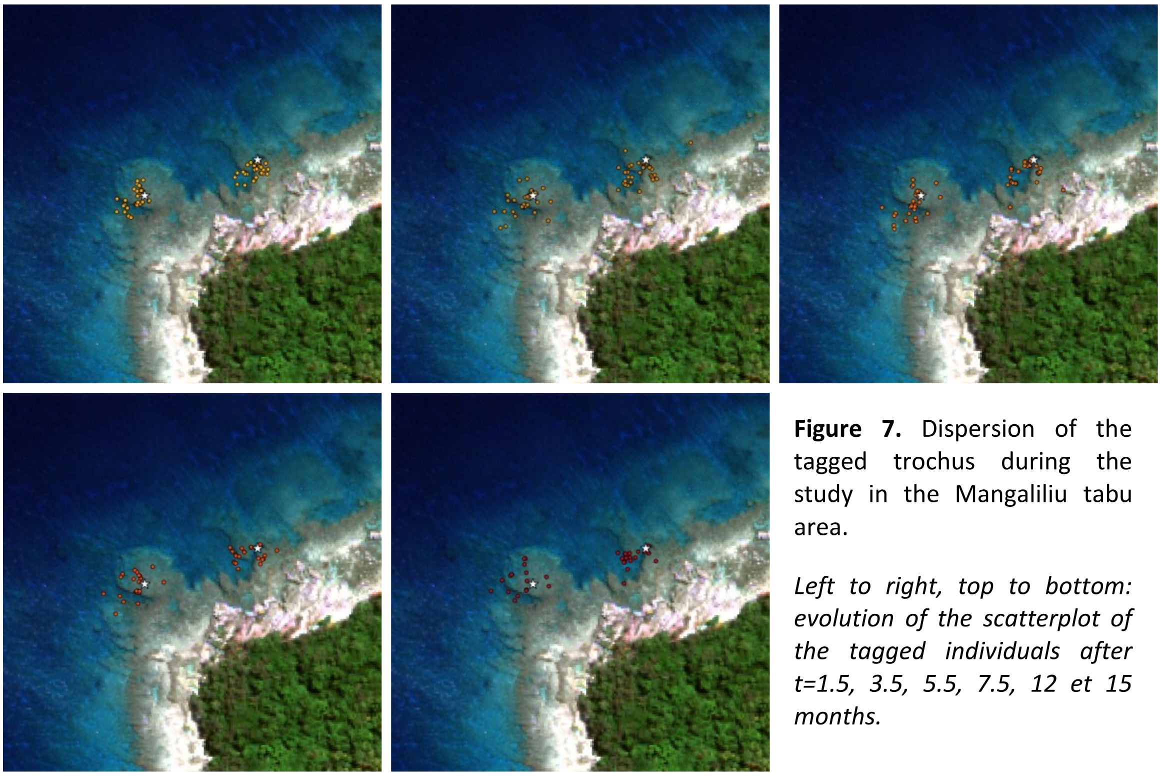

Figure 7. Dispersion of the tagged trochus during the study in the Mangaliliu tabu area.

Left to right, top to bottom: evolution of the scatterplot of the tagged individuals after t=1.5, 3.5, 5.5, 7.5, 12 et 15 months.

1.3.2 Accelerometer study

Accelerometers have unequivocally demonstrated that the activity of trochus is nocturnal: it begins at dusk and gradually stops just before sunrise (Figure 8). This nocturnal activity is characterized by short movements (<30 s) of low intensity (acceleration <0.12 g), most likely associated with foraging behavior. It is very likely that activity ceases when the animal reaches satiety.

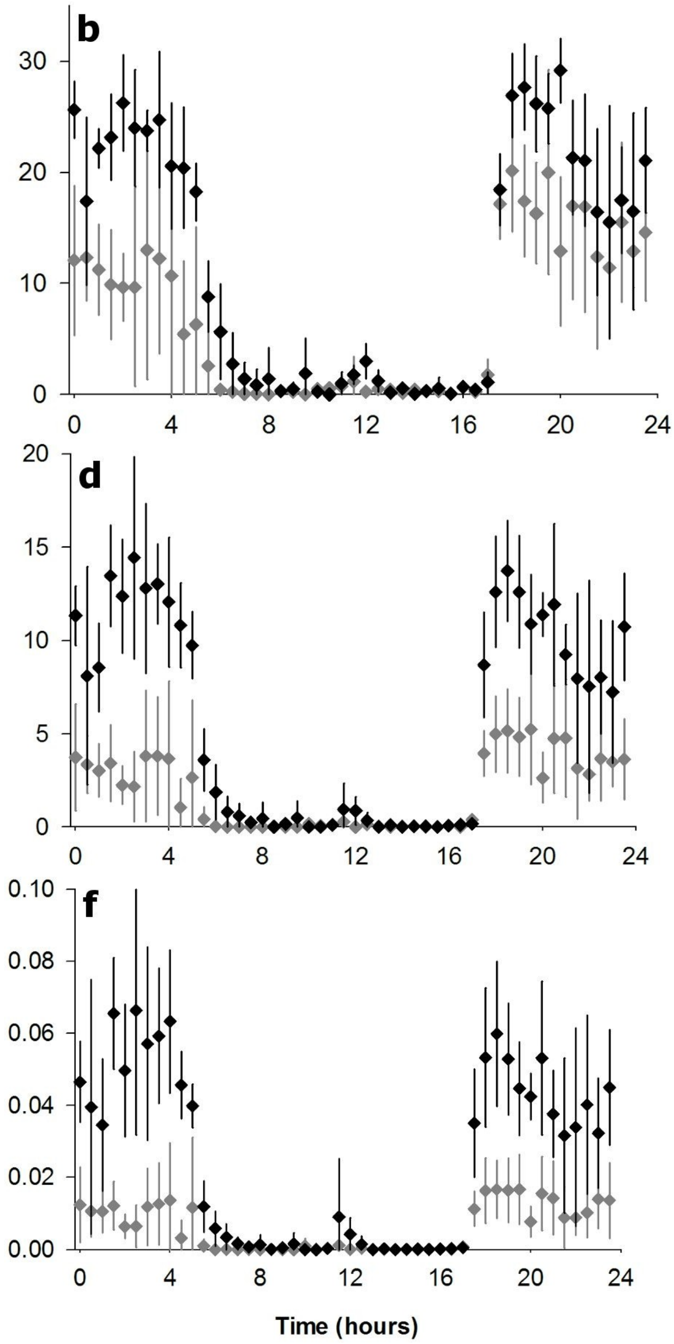

Figure 8. Number of movements, duration and speed for small (black) and large (gray) trochus measured using accelerometers sensors.

Behavioural analysis by size groups (80-90 mm vs. 120-140 mm shell basal diameter) reveals marked differences. Small individuals show greater activity as reflected by more intense, longer movements, thus corroborating the results obtained by direct underwater observations and subsequent trilatération analyses (see Figure 9).

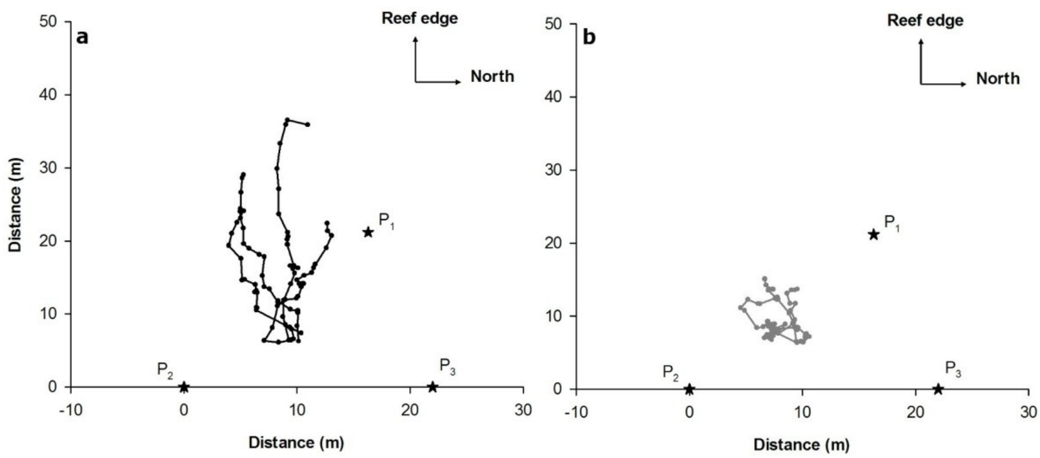

Figure 9. Cumulated displacement (in meters) of trochus over three days, estimated by trilateration from direct underwater observations. (a) small individuals (80-90 mm) (b) large individuals (120-140 mm). The position of the three reference stakes is indicated (P1, P2, P3).

Small individuals [diameters 79mm / 84mm / 89mm / 90mm] have clearly moved towards the reef, while large [128mm / 122mm / 136mm / 143mm] remained close to their starting point (Figure 9). These movements can reach more than 10 m in one night (30 m cumulated in 3 nights) and may correspond to the search for a more favorable habitat: trochus would leave the shallow reef flat to the outer reef where the depth and environmental conditions (substrate, power, food etc) are more ecologically favorable.

1.4. CONCLUSION - DISCUSSION

From a methodological point of view, the results obtained by tagging in all reef sites of the two tabu areas studied show high recapture rates, which are quite unusual in the marine environment. This emphasizes both the overall effectiveness of the techniques used (stainless steel tags screwed on the shell, participation of local fishermen for search surveys) and the sedentarily, low mobility of the target species (trochus).

Only a very limited number of tagged trochus were found dead (2 in Mangaliliu, 1 in Takara), confirming the absence of significant impact of the tagging technique employed here on the mortality of adult trochus. The durability of the tags appears, however, limited: because of corrosion, the screws tend to come off after a few months under water. In the vast majority of cases, it is possible to identify an individual as having been tagged at the start of the study, but without its corresponding ID. A modification of the tag fixation system would be therefore required to extend this approach beyond a few months, especially in the context of more comprehensive studies (eg. on growth).

The use of accelerometer sensors yielded very detailed information on the behavior of trochus under natural conditions. In particular, the ambiguity on their daily patterns of activity was lifted, highlighting exclusively nocturnal, very limited movements (of the order of a few meters per 24 hour period). In this context, accelerometry is a particularly interesting approach to identify changes in species behavior in response to environmental changes, a central topic in ecology which has very practical applications in terms of management.

From an ecological point of view, this study confirms the sedentary, nocturnal behavior of *Tectus niloticus*: the locomotor activity of the tagged individuals was restricted to night-time, with a complete cessation of movement during the day. This feature was especially pronounced for large individuals (older) that exhibited significantly lower activity than younger specimens. Our results also highlight the importance of the benthic environment (reef substrate) on the locomotor behavior of trochus. In optimal habitats (particularly reef flats or reef edges characterized by dominant bedrock cover, limited rubble cover and strong hydrodynamics), the displacement was very limited, probably confined to an area of a few meters radius around the night "refuge" of the animal. If the habitat is not perceived as favorable, however, significantly larger displacements are likely to happen: up to ten meters observed in one night.

Under normal conditions, adult trochus exhibit a very restricted home range. After a year, nearly 4 out of 10 tagged specimens were still found within 30 meters of their initial release position in Mangaliliu; 5 out of 10 tagged specimens were similarly found in Takara after 9 months. This rate is likely underestimated due to the cryptic nature of individuals, hidden in the crevices of the reef and therefore difficult to access during the day. It is very likely that additional tagged individuals were present in the search area, but were not detected. In fact the majority of individuals showed high site fidelity to very small reef area: some marked trochus were regularly found in the same place, within a few meters from the position occupied during the previous search surveys some months ago. These results were supported by both accelerometry and direct underwater observations.

Although the tagging techniques used in this study does not allow the reconstruction of the trochus trajectories between consecutive search surveys, they clearly support a high site fidelity of adult individuals with a home range restricted to a few dozen meters radius. It is likely that the location of this area is evolving over time, with a gradual movement of individuals on the reef in response to changes in food availability, density of conspecific or ontogenic changes in the behavior of individuals.

In terms of management, these results lead to the following conclusions:

- **Despite limited reef areas, the vast majority of tabu areas in Vanuatu most likely have sufficient size to provide effective protection to the population of adult trochus.**

As a direct consequence of specific behavioral features (sedentary, nocturnal), the home range of adult appears easily contained within the boundaries of the reserve usually encountered in the archipelago (i.e. a few hundred meters costal linear minimum).

- **The effectiveness of tabu areas to protect (accumulate) trochus adult biomass is highly dependent on the presence of suitable reef habitat.**

- **The ecological characteristics of trochus offer very interesting prospects for reseeding operations.**

The limited displacements and the high site fidelity observed have obvious advantages if one wishes to reintroduce trochus broodstock in depleted areas, since environmental conditions (especially benthic habitat and hydrodynamics) are favorable.

PART 2. EFFECTS OF THE MOVEMENTS OF FIVE REEF FINFISH SPECIES ON THE EFFECTIVENESS OF TABU AREAS

2.1. OBJECTIVES

As part of the first phase of the EFITAV project (2010-2012), three communities in the north of Efate island (Emua, Paonangisu, Takara) were selected to conduct an acoustic study of the movements of the Thumbprint emperor Lethrinus harak. This coastal species is indeed heavily targeted by fishermen in the area (see final report of the EFITAV 1 project - Dumas et al., 2012). To consolidate the results of this study, the second phase of the project was extended to five other fish species and to three communities of Pele island (Figure 10). Pele and Efate islands on the one hand, and Efate island and a small sandy island in Takara village on the other hand, are separated by a 500 m deep and 30-40 m wide channel exposed to strong tide currents.

In particular, fish movements have been studied within and out of the marine reserves in Takara (linear coverage: 1000 m) and Worasiviu (linear coverage: 460 m) villages to help in defining the appropriate size and location of both tabu areas according to target resources. Results will be used to support local management systems. The conditions and limits for generalizing these results to other islands will be discussed with the support of the literature.

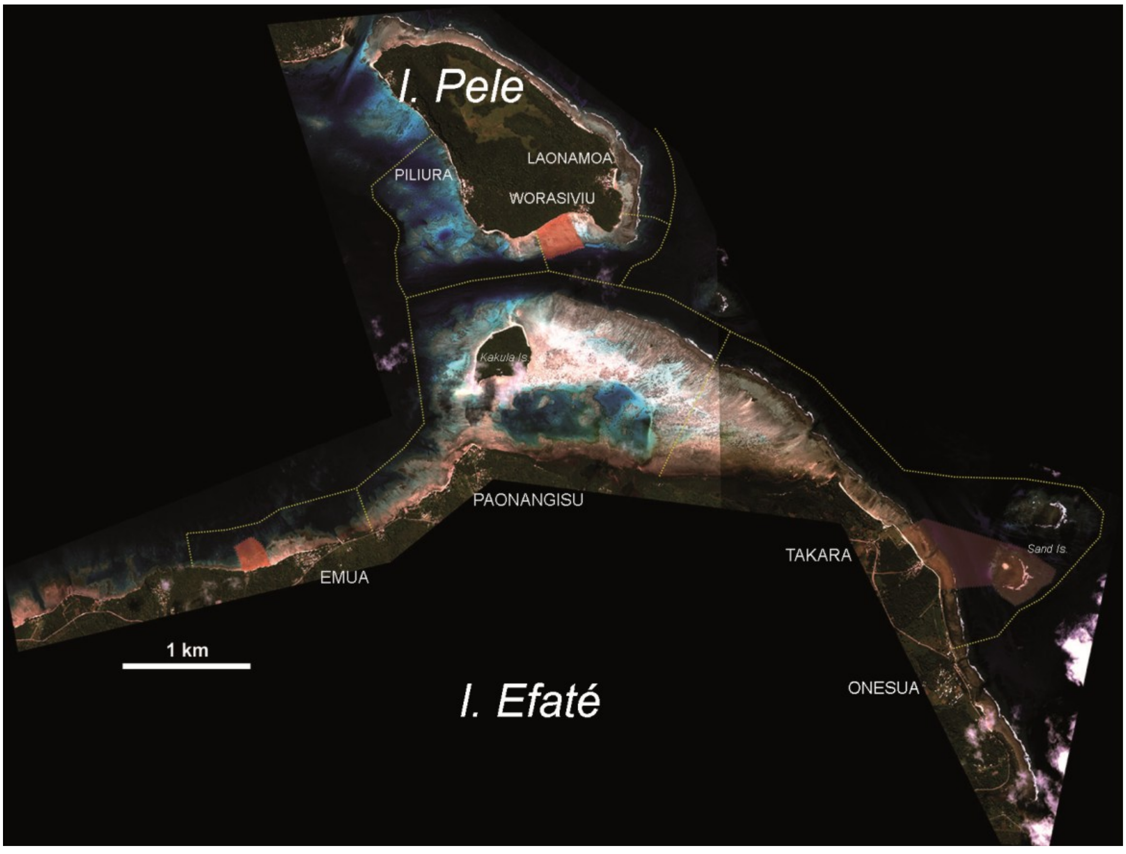

Figure 10. Study area for fish acoustic tagging during the EFITAV project (phase 1/2010-2012 & phase 2/2013-2014) in Efaté and Pele islands (Vanuatu). Yellow dashed lines represent approximate village marine boundaries. Transparent red areas show the marine reserves (tabu areas) in Emua, Takara and Worasiviu villages.

2.2. DATA COLLECTION AND ANALYSIS

2.2.1 Tagged species examined and acoustic array

A network of 32 omnidirectional VR2W VEMCO hydrophones was set up in January and February 2013 on the outer reef slope (between 3 and 23 m depth) over about 10 km (Figure 11). The hydrophones have been positioned on Pele island, Efate island and the sandy island to assess fish movements along fringing reefs and across channels. To ensure consistent acoustic detection, the hydrophones were attached to the substrate or to 80 kg cement blockst.

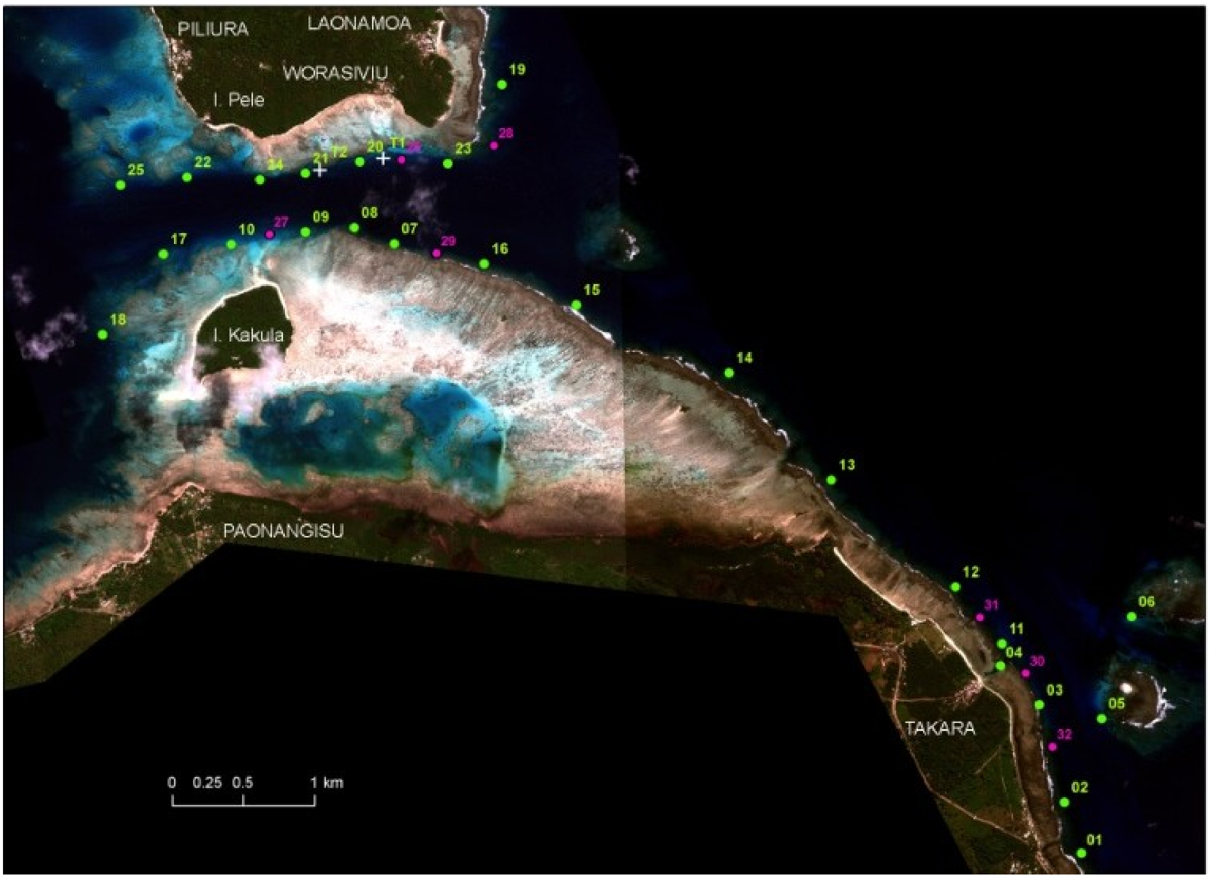

Figure 11. Disposition Acoustic array of 32 hydrophones that was deployed over the reef areas in Efaté island, Pele island and the sandy island in Takara village. Some hydrophones (n=16, pink spots) were made available by the Aquarium des Lagons of New Caledonia (ADL) and Reef Explorer Fiji.

Five species were studied: the Bluespine unicornfish (Naso unicornis) and four parrotfish species (Scarus altipinnis, Scarus ocellatus, Cetoscarus microrhinos and Scarus oviceps)

(Table 1 and Figure 12). These species are commonly targeted by fishers using gillnets and spearguns in the area, as in other islands of Vanuatu.

Figure 12. Target fish species: the Bluespine unicornfish (*Naso unicornis*) and four parrotfish species (*Scarus altipinnis, Scarus ocellatus, Cetoscarus microrhinos* and *Scarus oviceps* (from left to right).

Tableau 1. Location of tagging sites and respective number of tagged fish

		Number of tagged fish					
SITE	**TAGGING DATE**	***Naso unicornis***	***Scarus altipinnis***	***Scarus ocellatus***	***Cetoscarus microrhinos***	***Scarus oviceps***	**TOTAL**
PAONANGISU	04/09/2013		6		2		**8**
	06/09/2013	2				5	**7**
	07/10/2013	4		2	1		**7**
WARASIVIU (Pele Is.)	10/07/2013			2	3		**5**
Tabu area	05/09/2013	4	2	3	2	1	**12**
PILIURA (Pele Is.)	07/10/2013	2	1		1		**4**
TAKARA	03/09/2013	6			5		**11**
Tabu area	08/10/2013		6				**6**
TOTAL		**18**	**15**	**7**	**14**	**6**	**60**

A total of 60 fish were caught by scuba divers at night at new moon during three 2-5 days tagging surveys in July, September, and October 2013 (Table 1). The fork length of each fish was measured and ranged between 26 and 58 cm. An acoustic V8-4x VEMCO transmitter was installed in the abdominal cavity of the fish through surgery while the fish was anesthetized (Figure 13). To maximize battery life and to track fish movements over a period consistent with the study objectives, the transmitters were programmed to send signals for 365 days at intervals of 160s ± 60s. After suturing the incision, each fish was placed in a floating cage for at least two hours to allow him to recovering from the anesthesia. To reduce the stress of capture and surgery, the fish were handled as little as possible and released the next day of capture at sunrise at the place where they were captured.

Hydrophones recorded the transmitter identification number and the detection date and time when the fish came within the detection range. The in situ detection range of each hydrophone was previously measured using a V8 test transmitter and ranged from 40 m to 150 m depending on reef complexity. The passive recording of acoustic data began in July 2013 and was completed in October 2014. The data were offloaded once every two months, which also allowed to cleaning the hydrophones to ensure good signal reception.

Figure 13. The fish were anesthetized and equiped with V8-4x VEMCO acoustic transmitters in the abdominal cavity using surgery.

The field work was labor intensive and required IRD, ADL, Vanuatu Department of Fisheries staff, additional divers, and local fishermen to maximize the chances of catching the target species. Despite bad weather conditions delayed the survey activities, the tagging plan was eventually completed.

2.2.2 Estimation of home range

The fish detection data were transcribed into "centers of activity" (COAs) corresponding to the average detection position for six hours windows. To make this average position more realistic, each detection is associated with a position taken at random in the detection area of the corresponding hydrophone (and not with the exact position of the hydrophone on the reef floor). The fish trajectory was thus estimated by four COAs (ie, 4 average positions) per day: in the morning (3 - 9 am), at mid-day (9 am – 3 pm), in the evening (3 – 9 pm) and at night (9 pm - 3 am).
Three virtual lines linking the hydrophones alongside the reef drop-off of the three islands in the survey area were used (Figure 14) to map the COAs of each fish. This approach allowed to using the Kernel Density Estimates and Kernel Utilization Density index to assess habitat use. We defined the areas corresponding to an estimated presence of each fish for 50% (KUD50) and 95% (KUD95) of his total detection time. The KUD50 was considered as the core area of the fish home range. Fish may do some excursions out of this core area most of which are contained in their 95% utilization area. However, few distant excursions were recorded outside of KUD95 area for some fish. Spatial habitat use was mapped for easy interpretation of fish home range.

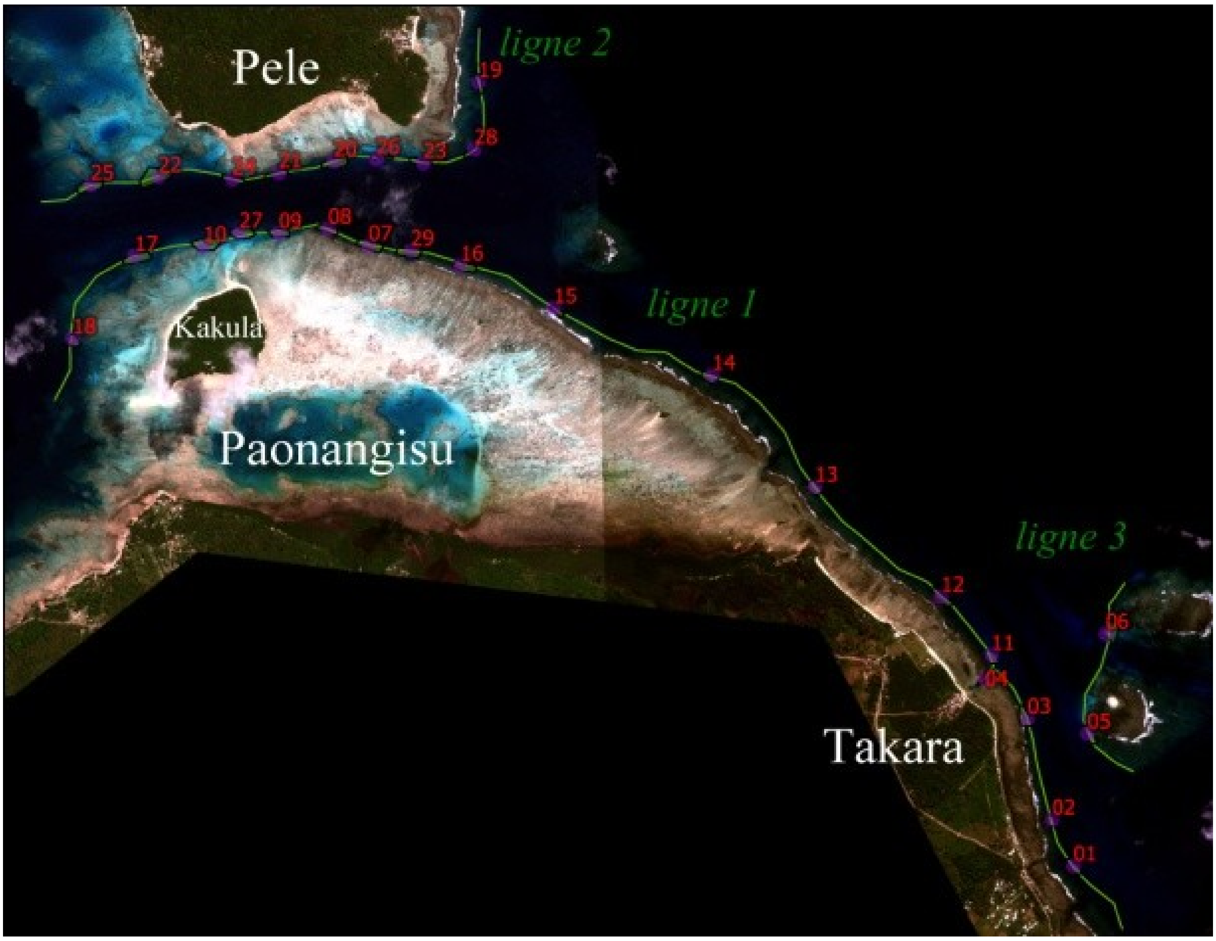

Figure 14. The fish home range was estimated alongside three virtual lines linking the hydrophones of each island.

Finally, the following parameters were estimated to characterize the spatial and temporal use of the fish home range:

• linear extent of the core area (KUD50)

• linear extent of KUD95 area (considered as the extension of the estimated home range and reflecting the distance covered during trips)

• frequency of excursions,

• duration of excursions.

The behavior of fish was then compared by the method of MultiDimensional Scaling (MDS), which allows for visually representing the similarity between fish (depending on their size, species, etc.). Considering that fish that are close in the MDS space show similar behavior, this method was used to define behavioral groups.

2.3. RESULTS

2.3.1 Detection of tagged fish

Observations show a 90% postoperative survival rate. Six parrotfish died within 24 hours following tagging (2 S. altipinnis, 2 C. Microrhinos, 1 S. bicolor and 1 S. oviceps). In total, the results below therefore relate to 54 fish.

Of these, 12 fish (22%) traveled more than 4 km from their release site, and were occasionally detected in the network. These fish are the most mobile fish during the study and belong to different species. In the majority of cases (67%), these fish have not left the island on which they were captured and tagged, but rather have moved along the reef crest of the island of Efate or Pele respectively. This is particularly the case for 6 small unicorn fish (26-31 cm) tagged on the Paonangisu reef: they remained in the study area between one week and two months and then suddenly disappeared after moving southward up to 8 km from the release site (the last detections were recorded by Takara hydrophones at different times). This behavior suggests that their home range extends beyond the study area: they may have been caught during the tagging surveys while they were on a long-distance excursion or relocated their home range for some time after tagging. No other species showed similar behavior.

The other five fish (33%, 2 C. microrhinos and 3 N. unicornis) have crossed the channel between Efate and Pele islands and / or between Efate island and Takara sandy islet. These channels are about 500 m wide and 30-40 m deep. The results showed that these natural boundaries were not impassable barriers for these adult fish.

A second group of 13 fish (32%) of different species was detected for less than 20 days, or sporadically for more than one month. The interpretation of these results is unclear: it is possible that these fish were more often present in non-detection zones within the study area (ie, between the hydrophones), and / or have made regular trips within and out of the study area. The highly mobile fish behavior described above in the first group of fish makes these assumptions plausible.

Fish of the third group (29 fish, 54%) were detected frequently over more than 40 days (except for a fish, 16 days). Data allowed for further analysis of their home range, as described below.

2.3.2 Home range analysis

Three very distinct types of behavior were observed among the 29 frequently detected fish (Figure 15). Overall their characteristics were as follows (Figure 16):

- a group of 17 sedentary fish (59%) presented small home range (100-700 m) and core area (<150 m) and made rare excursions (group A): their size was usually moderate (average length 37 cm) and they belong to the five tagged species.

- a group of 7 large mobile fish (24%) presented large home range (1100-2300 m) and core area (400-700 m) and generally made frequent excursions (group b): these fish were large (41-58 cm) and belong to two species: C. microrhinos and S. altipinnis.

-a group of 5 fish (17%) presented medium-size home range (500-1100 m) and core area (100-200 m) (group ab): their size were highly variable and belong to three species: C. microrhinos, S. altipinnis and N. unicornis.

The estimated parameters (fish length, linear extent of KUD50 and KUD95 areas, frequency and duration of excursions) showed no significant differences between species, suggesting that fish behaviors were broadly similar among the five species. The duration of excursions outside core areas was not significantly different between groups (Figure 16).

Furthermore, the fish that were tagged in the Takara marine reserve were absent from group b, reflecting smaller mobility and home range than those of the fish from other villages. Although the interpretation of this difference is uncertain, the presence of a deep channel (6-8 m) that was unique in the study area could partly explain this difference.

The above typology suggests that larger fish tend to use larger reef areas than smaller fish, however this relationship was not invariable. Some large tagged individuals showed sedentary behaviors while some smaller individuals were particularly mobile. It is useful to remind here that these results relate to 29 of the 54 fish for which acoustic data were recorded. For example, long excursions were observed in six small unicorn fish that were not included from the home range analysis (see previous paragraph).

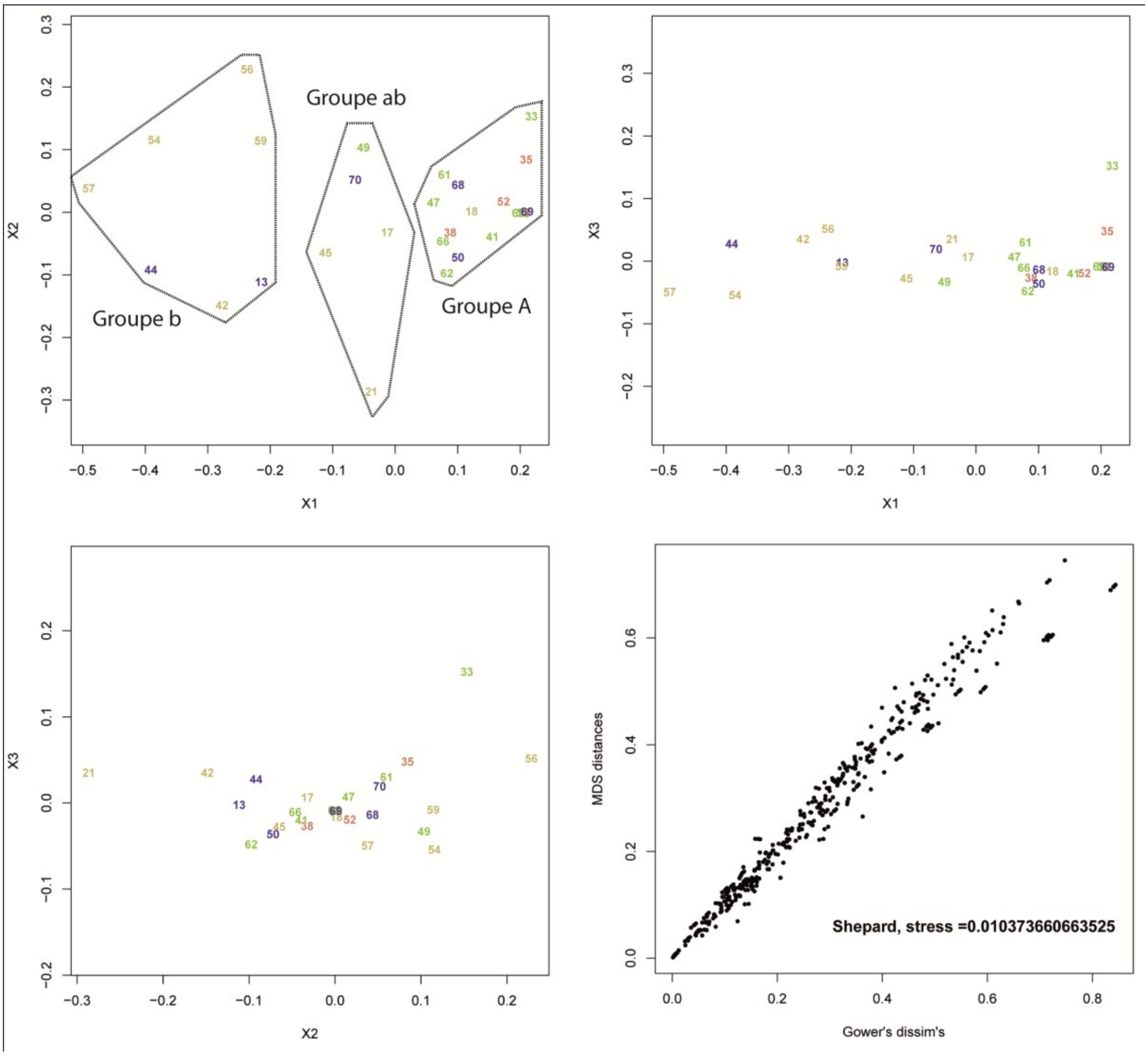

Figure 15. Typology of fish behavior through MDS analysis. The three groups are shown (upper left corner) and include 17 fish (group A, 5 species), 5 fish (group ab, 3 species) and 12 fish (group b, 2 species). Blue : C. microrhinos; beige : S. altipinnis ; brown : S. oviceps ; green : N. unicornis ; turquoise (group A) : S. ocellatus

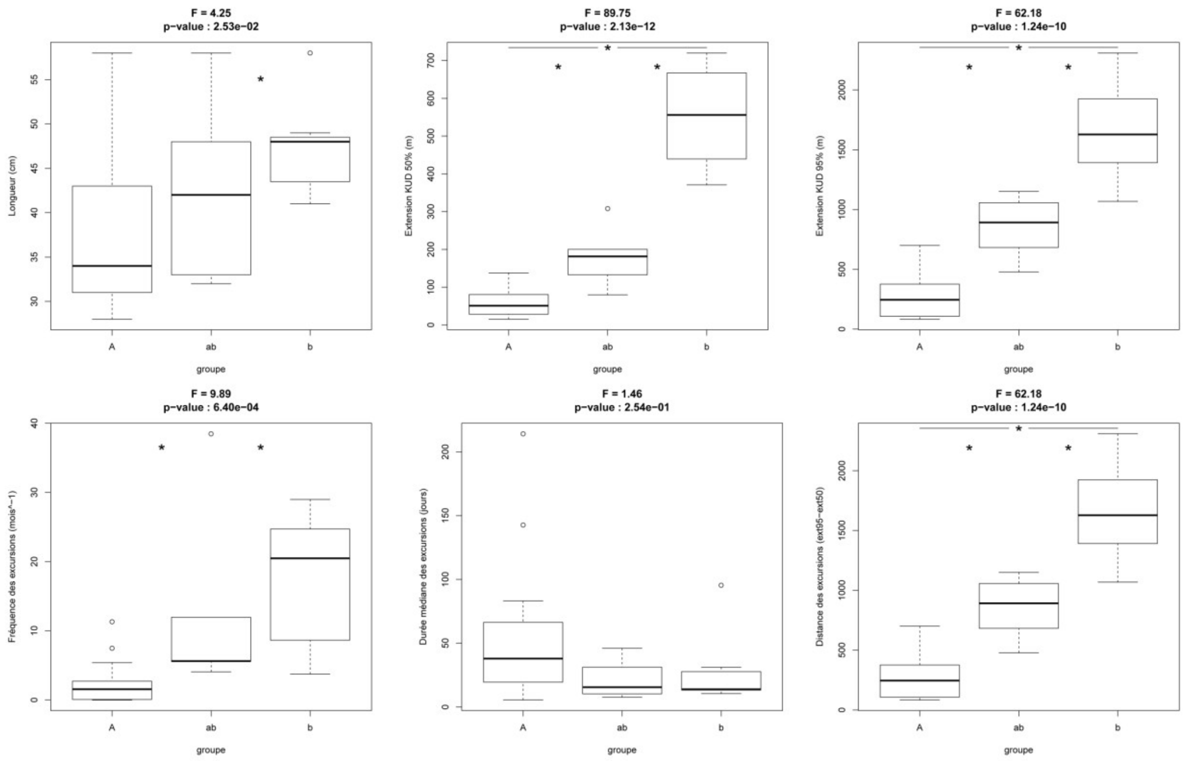

Figure 16. Characteristics of the three behavior groups detected by the MDS analysis : fish fork length, linear extent of the core area (KUD50), linear extent of the estimated home range (KUD95), and frequency, duration and distance of excursions. *: significant differences between groups (ANOVA, P<0.05).

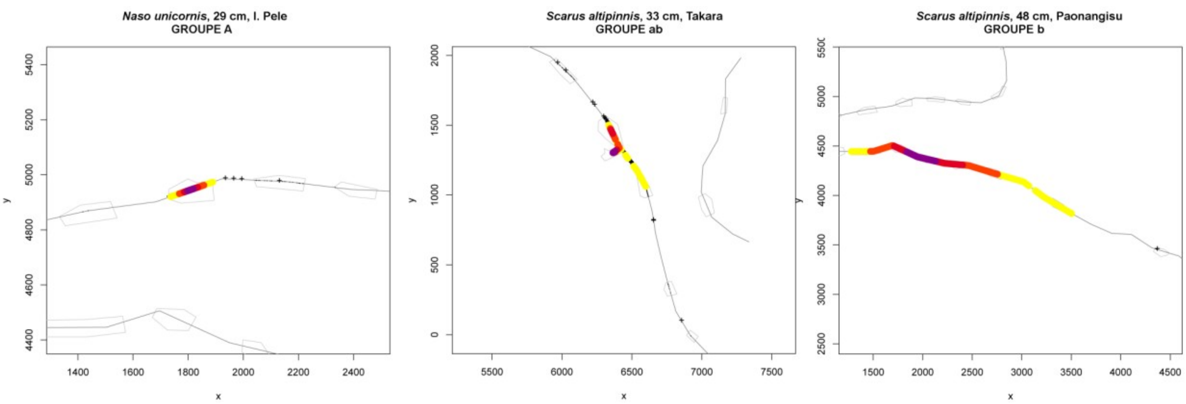

Figure 17. KUD maps of three fish belonging to each behavior group A, ab, et b (cf. Figure 15). Purple and red area : core area (KUD50) ; coloured area : home range (KUD95). Black lines: reef drop-off. Units of axis: meters.

2.4. DISCUSSION AND CONCLUSION

The movements observed for each species (*Naso unicornis, Scarus altipinnis, Scarus ocellatus, Cetoscarus microrhinos* and *Scarus oviceps*) showed that the temporal and spatial use of the home range (ie, distances and frequency of movements) greatly varied across fish.

When there was sufficient data (ie, for about half of the fish), home range was estimated between 100 m and 2300 m, although some fish have made much longer trips over several km. In 50% of cases, it extended over 100- 500 m and over 1000 m in 25% of cases. The mobility of fish tended to increase with their size, even if the relationship was not invariable.
In our study area, two marine reserves stretch over 460 m and 1000 m in Worasiviu and Takara villages, respectively. If one considers that the protection of an adult fish is effective when its home range is included in the protected area, the latter must be large enough to account for fish movements and located on suitable habitats. For instance Worasiviu marine reserve would only protect very sedentary fish, i.e three out of the twelve fish (25%) tagged in Pele island (three specimen of *S. oviceps, N. unicornis,* and *C. ocellatus*) in our study. On the contrary, eight of the ten fish tagged in Takara marine reserve (80%, ie. all fish tagged on this site except two large individuals of *C. microrhinos* and *N. unicornis*) would be effectively protected. The effectiveness of this reserve is well perceived by the community, who conducts collective fishing once or twice a year.

It is interesting to note that the variability in the extent and utilization of the home range showed no significant difference between the five species. Indeed the variability of fish behavior between individuals of the same species was similar as (or even higher than) that between species. Although generalizing this result is not straightforward given the small sample size, it highlights the ability of marine reserves to manage multiple resource species. **This study highlights the need to protect reef areas extending at least over 1000 m to 2000 m in appropriate habitats in order to take into account the wide variety of reef fish behavior, and to provide sufficient protection to most of them, especially the larger ones.** Small reserves can protect sedentary fish and sometimes big fish as shown in our study. However although this effect may be perceived by communities, our results suggest that this should not mask the fact that this protection would benefit only a small part of fish resources.

Given the fish movements observed, it has been recommended to extend the boundary of Takara marine reserve 300-500 m northwards, and the boundary of Worasiviu marine reserve 500 m westward. In the latter case, the protected area would extend into the neighboring Piliura village (see Figure 10), which has already set aside another area of his customary marine area located on the west side of Pele island. Therefore the issue would be to strengthen cooperation between these villages to coordinate local management rules, because fishermen of these villages sometimes target the same fish according to their movements. In some cases, extending tabu areas to improve their effectiveness may lead to significant proportion of customary marine areas to be closed and/or to weak enforcement (if boundaries are too far away from the village for instance). Rather than setting up small reserves that would hardly provide sufficient biomass increase, community efforts could be directed to other management measures to better control fishing pressure.

More broadly, the results suggest to design fishing restrictions not only at village level given the spatial scale of fish movements. The inherent limitations of community-based management approaches in Vanuatu islands shall be recognized, particularly in the more populated islands where distances between villages are small. Inter-village management agreements and the implementation of national regulations concerning reef finfish (eg mesh sizes of gillnets) are recommended.

These results are consistent with other acoustic studies on reef fish, including those obtained during Phase 1 of the EFITAV project for the Thumbprint emperor *Lethrinus harak* (Dumas et al., 2012). Our recommendations concerning the management of reef finfisnh resources and tabu areas in particular could therefore be useful in other Vanuatu islands whose reef geomorphology and marine habitats are similar to those of our study area (eg. continuous fringing reefs bordering mountainous islands).

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