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# Decadal increase in the number of recreational users is concentrated in no-take marine reserves

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**Abstract :**

In coastal areas, demographic increase is likely to result in greater numbers of recreational users, with potential consequences on marine biodiversity. These effects may also occur within Marine Protected Areas (MPAs), which are popular with recreational users. Our analysis builds on data collected over a ten-year period during three year-round surveys to appraise changes in recreational boating activities in coral ecosystems. Results show that the number of boaters has greatly increased, particularly so within MPAs during weekends and the warm season, when peaks in boat numbers have become more frequent. We also observed that the number of anchored boats has increased over the period. These changes may be resulting in biophysical impacts that could be detrimental to conservation objectives in MPAs. This steady increase over time may cause changes in the spatial and temporal distribution of users and in their practices, thus highlighting the importance of monitoring recreational activities.

**Highlights**

► Boating activity was monitored over ten years in an MPA network. ► Boaters' number has strongly increased particularly so within MPAs. ► Boaters' especially increased during weekends and summer. ► Peaks in boat numbers have become more frequent and higher. ► Recently installed permanent moorings did not prevent increased anchoring in MPAs.

**Keywords** : Recreational uses, MPA, Coral reef ecosystem, Spatio-temporal pattern, New Caledonia, Mooring practices

## 1. Introduction

In recent decades, coastal areas have been facing a substantial increase in both demography (Vallega, 2001; Duedall and Maul, 2005) and touristic development (Davenport and Davenport, 2006). As a consequence, recreational uses have increased and diversified (Chaboud et al., 2004; Widmer and Underwood, 2004; Monz et al., 2010). In particular, leisure transport has increased in a non-linear fashion with considerable impact on the coastal environment (Davenport and Davenport, 2006). Recreational uses are of importance in coastal areas (Kenchington, 1990), as has been shown for various regions of the world such as the Great Barrier Reef (Kenchington, 1993), Sydney harbor in Australia (Widmer and Underwood, 2004), Narragansett Bay in Rhode Island, USA (Dalton et al., 2010) and in Majorca, Spain (Balaguer et al., 2011).

Marine Protected Areas (MPAs) are now a central tool for ecosystem-based management of coastal and marine areas (Agardy, 2000; Browman and Stergiou, 2004). Their number and area is increasing worldwide (Wood et al., 2008; De Santo, 2013) in order to meet the international targets set by the World Summit on Sustainable Development (WSSD, http://www.un.org) and the United Nations Convention on Biological Diversity (CBD, https://www.cbd.int/web/default.shtml). MPAs may have a positive effect on visitor numbers, with subsequent benefits for the local economy (Alban et al., 2008). This increase may in turn support their existence or establishment despite their cost (Balmford et al., 2004). Recreational non-extractive users (i.e. excluding any kind of fishing) are generally authorized within MPA boundaries (Shivlani and Suman, 2000; Smallwood et al., 2012a). It may therefore be hypothesized that in coastal areas the proportion of such users will increase as more MPAs are established, which in turn may become a concern for the attainment of MPA management goals. Many studies have demonstrated that recreational non-extractive activities result in specific disturbances to and impacts on habitats and species, depending on user numbers and practices. For instance, anchoring has been shown to impact the composition and cover of marine biotic habitats (Walker et al., 1989; Glynn, 1994; Backhurst and Cole, 2000; Milazzo et al., 2002; Milazzo et al., 2004; Saphier and Hoffman, 2005; Davenport and Davenport, 2006; Lloret et al., 2008; Maynard et al., 2010). Trampling by recreational users in very shallow water (Leujak and Ormond, 2008) has similar impacts on habitats (Kay and Liddle, 1989; Neil, 1990; Rodgers and Cox, 2003; Juhasz et al., 2010) and on macro-invertebrates (Brown and Taylor, 1999; Casu et al., 2006). Boat traffic emerges as a source of disturbance for fish (Codarin et al., 2009; Slabbekoorn et al., 2010; Whitfield and Becker, 2014) and mammals (Bejder et al., 2006; Hodgson and Marsh, 2007; Rako et al., 2013; Merchant et al., 2014).

As well as conservation objectives, MPAs frequently seek to achieve socio-economic management goals (Claudet and Pelletier, 2004; Pomeroy et al., 2005; Pelletier, 2011), including the maintenance of sustainable uses. However, local density of boats has been shown to negatively affect boaters' satisfaction and their perception of safety levels (Ashton and Chubb, 1972). High local density of boats also increases the likelihood of conflicts between recreational boaters, especially near large metropolitan areas (Heatwole and West, 1982). Boat density, however, is not the only identified cause of such conflicts. Specific recreational craft such as jet-skis are associated with disturbance and give rise to conflict among users, even though relatively few people use them (Widmer and Underwood, 2004).

The number of recreational users has been identified as the main information on uses required for protected area management (Griffin et al., 2010). However, although this overall number is informative, it reflects neither the spatial and temporal distribution of users nor the variety of activities practiced (Gray et al., 2010). Such information is necessary for design and site selection of MPAs (Parnell et al., 2010), for assessing human impacts on biodiversity (Chabanet et al., 2005) and MPA efficiency (Pelletier et al., 2005), and consequently for adapting management strategies to mitigate these impacts (Davenport and Davenport, 2006; Lloret et al., 2008).

The lack of spatial data on recreational uses in the marine environment was previously reported (e.g. St. Martin and Hall-Arber, 2008) and accounted for by the logistics needed to survey dynamic and ephemeral activities in often extensive coastal and marine areas (Smallwood et al., 2011). However, in recent years several studies have assessed spatial patterns in recreational uses from field data (see references below). They show that the spatial distribution of boaters depends on factors such as habitat type, adjacent land tenure, MPA setting, boat type (Sidman and Fik, 2005; Dalton et al., 2010; Smallwood et al., 2011), and activity (Shivlani and Suman, 2000; Smallwood et al., 2012b). To our knowledge, there is no study documenting the inter-annual evolution of such spatial patterns, although it might be expected that the increase and diversification of recreational activities are likely to affect the spatial distribution of users.

Like spatial patterns, the short-term temporal distribution of recreational users depends on boat type and activity (Smallwood et al., 2011). A number of studies show that several factors significantly influence the number and spatial distribution of boats, including season, day type and weather conditions (Kuentzel and Heberlein, 1992; Smallwood et al., 2012a; Smallwood et al., 2012b; Smallwood, 2011; Martin and Hall-Arber, 2008; Gray et al., 2010; Dalton et al., 2010; Widmer and Underwood, 2004; Balaguer et al., 2011; Navarro-Jurado et al., 2013). These studies show that more boats are observed at weekends and on bank holidays (e.g. National Day), during summer months and when the weather is sunny (Widmer and Underwood, 2004; Smallwood and Beckley, 2008; Dalton et al., 2010; Smallwood et al., 2011). All together these factors were found to partly explain intra-annual variations of recreational use. But there is no study about possible changes in the relative importance of these factors over years. Such information would certainly help to anticipate expected user pressures and adapt management strategies accordingly, in order to i) mitigate the consequences of high use level on biodiversity and ii) maintain user satisfaction and safety (Davenport and Davenport, 2006). In particular, crowding – defined here as extreme values (peaks) in user numbers – is likely to cause the displacement of users and thus influence their distribution at several spatial scales. We could find no published study addressing the evolution either of peak event frequency or of their magnitude.

This paper aims to assess spatial and temporal patterns of recreational users over a decade in a coastal area that has been subject to a marked demographic increase over the same period. This area is located in a coral reef ecosystem and encompasses several no-take reserves where boat access is permitted. We first studied changes in the distribution of users inside and outside these reserves, both overall and per boat type. In a second stage, we examined the influence of short-term temporal factors, such as season and day type (weekday versus weekend) on mean boat numbers and on the occurrence of peak numbers. Lastly, we investigated changes in mooring use as a consequence of increasing numbers of recreational boaters.

## 2 Materials and methods

### 2.1 Study site

New Caledonia is located in the South Pacific approximately 1500 km north-east of Australia. The New Caledonian lagoon has an exceptionally high diversity of habitat (Andrefouët and Torres-Pulliza, 2004), fish (Chabanet et al., 2010), and emblematic species such as turtles and dugongs. Eighty percent of the lagoon surface area was inscribed on the World Heritage list in 2008 (David et al., 2010). Most of the population lives in the Noumea area, which encompasses the cities of Noumea, Païta, Dumbea and Mont-Dore (Fig. 1) with around 180,000 people in 2014, according to the latest demographic census taken in 2014 (ISEE, 2014) (Fig. 2). The population of Dumbea and Païta increased at a rate of 5% per year between 2004 and 2014, twice the increase rate of Noumea city and of New Caledonia as a whole. This study focuses on the islets and reefs in the lagoon facing the Noumea area.

Boating is a highly popular recreational activity in New Caledonia: in 2014, 8% of Noumea area inhabitants owned a boat, as against 6.4% in 2004 (Fisheries Office of the New Caledonian Government, unpublished data. Fig. 2). There are numerous boating amenities (mainly launch ramps) in the Noumea area. In the last decade, the number of registered recreational boats in the Noumea area increased to more than 14,100 in 2013, of which 38% were motorboats, 8% jet-skis, 8% sailboats and 46% other types of boat according to official data from the New Caledonian government. This sharp increase in boat numbers has become a concern for environmental management and especially for lagoon management.

Among the many reefs and islets in the study area (Fig. 1), we selected eleven sites (seven islets and three reefs), located within 10 nautical miles from the Noumea area, all of which are popular destinations for recreational boaters. The selected sites include two no-take MPA islets and one no-take MPA reef, where all extractive activities (fishing and shell collection) are banned, but entry is not restricted. Inside these MPAs, thirty-eight permanent moorings were installed before 2012 and four more since then. The two protected islets have a number of amenities, such as shelters, barbecue sites, a pontoon, a botanic path, information signs and dry toilets (installed between 2010 and 2013). The three MPAs are among the closest sites to Noumea city, where the majority of launch ramps and marinas are located.

### 2.2 Data collection

For this study, we used count data of recreational boats recorded over three year-round periods of time, in 2005/2006, 2008/2009 and 2013/2014. Field trip planning was temporally stratified per day type (weekday and weekend) and season (cold and warm season) (Table 1). The cold season lasts from May to October and the warm season from November to April. Forty-three aerial trips were undertaken from March 2005 to February 2006 (Jollit, 2010), 45 boat trips from March 2008 to February 2009 (Preuss, 2012), and 30 aerial and boat trips from March 2013 to February 2014.

Each site was observed at a close distance to ensure the identification of boat type and mooring type for each boat. The duration of a trip was around one hour for an aerial survey and two to three hours for a survey by boat. In 2013, six paired aerial and boat-based trips were conducted to investigate the consistency of the data collected from the two methods. Results of Wilcoxon tests indicated no significant difference in the overall number of boat counts between aerial and boat-based surveys at 5% error rate. This was also the case for boat counts per boat type and per mooring type.

Day trips took place between 8 am and 4 pm. All day trips in 2005 were conducted before noon. A Mann-Wittney test conducted on 2008/2009 and 2013/2014 data indicated no significant difference in boat numbers between morning and afternoon at 5% error rate.

At each site, observers counted boats and recorded boat type and mooring type, except in 2005, when mooring type was not recorded. Although fishers were also recorded, we focused here on non-extractive activities, as we were mainly interested in no-take MPAs. Boat type included sailboat, motorboat, dinghy and jet-ski. Compared to motorboats, dinghies were smaller than 5 meters and the pilot was situated at the rear of the boat with the helm of the motor. Mooring types included: 1) anchored boat; 2) beached (only occurs on islets); 3) boat on a permanent mooring (only at MPA sites (Fig. 1)) and 4) boat at a pontoon (only at Signal islet) (Fig. 1).

During each trip, information on weather conditions was recorded: 1) qualitative scoring of weather (sunny and cloudy/rainy); 2) wind direction and 3) wind strength (Table 2).

## 2.3 Data analysis

### 2.3.1 Boat numbers: estimates and spatial distribution

Spatial distribution of recreational boats is known to depend on several factors including boater activity, boat type, weather, location of boating facilities, geographic factors or a combination of the above (Widmer and Underwood, 2003; Dalton et al., 2010; Gray et al., 2011). In the present analysis we considered four types of site according to reef type (islet or reef) and protection status (inside or outside MPA), and we computed boat numbers for each combination of these, both per boat type and for all boat types combined.

The sampling design was stratified with four temporal strata corresponding to a combination of 2 day types (weekday and weekend) and 2 seasons (cold and warm). Following simple random sampling within each stratum, the mean number of boats and associated variance were computed per site type for each stratum:

$$\begin{cases} \overline{N}_{st} = \dfrac{\sum_{i=1}^{d_t} n_{ist}}{d_t} \\ \hat{V}\left(\overline{N}_{st}\right) = \left(\dfrac{1}{d_t(d_t-1)}\left(1-\dfrac{d_t}{D_t}\right)\right) \times \sum_{i=1}^{d_t}\left(n_{ist}-\overline{N}_{st}\right)^2, \end{cases} \qquad (1)$$

where $n_{ist}$ denotes the number of boats observed at site type *s,* during day trip *i*, for temporal stratum *t*, $d_t$ is the number of day trips in stratum *t*, and $D_t$ is the number of existing days in stratum *t* (i.e. stratum size).

The mean number of boats per day trip at site type s and associated variance were derived from (1) by averaging over strata:

$$\begin{cases} \overline{N}_s = \sum_{t=1}^{4} \frac{D_t}{\sum_{t=1}^{4} D_t} \times \overline{N}_{st} \\ \hat{V}(\overline{N}_s) = \sum_{t=1}^{4} \left( \frac{D_t}{\sum_{t=1}^{T} D_t} \right)^2 \hat{V}\left(\overline{N}_{st}\right), \end{cases} \tag{2}$$

In addition to boat numbers, boat densities were computed from mooring areas (in $km^2$) based on the envelope of the area where boats were moored in 2013. The envelope was determined using Geographical Information System Software (ArcGIS 10.2®).

A peak in boat numbers is defined here as an exceptionally high count value compared to the average count. It may be defined at several spatial and temporal scales. We could find no published definition of a peak. A boat count peak was thus defined here as the 90% percentile of the distribution of boat numbers observed per day trip. Two periods of time were considered for determining percentiles: 1) each surveyed year and 2) all surveyed years. The first definition allowed us to identify, within each year, the conditions that significantly explained peaks, while the second enabled us to determine whether the occurrence of peaks changed from year to year.

The total number of visitors was identified by Griffin et al. (2010) as the major piece of information required for managing use pressures. In the present study we considered the number of boats per boat type and overall as well as the occurrence of boat count peak, and we counted the number of boats per mooring type.

### 2.3.2 Weather description

A typology of the weather conditions encountered during the 118 sampling day trips was obtained by performing a Multiple Correspondence Analysis (MCA) followed by a Hierarchical Ascending Clustering (HAC) based on Ward's agglomerative criterion. The typology relies on three qualitative variables: weather perception, wind speed and wind direction (Table 2). The number of clusters was determined based on the highest jump of variance of the HAC.

### 2.3.3 Statistical analysis

The influence of temporal factors on each metric calculated from boat activity was investigated using Generalized Linear Models (GLM) (Table 3). Weather typology was included in each model instead of the three qualitative variables (see § 2.3.2 above). A negative binomial distribution was considered for modeling boat counts and a binomial distribution for the occurrence of boat count peaks.

For each metric, model selection was based on the likelihood ratio test (Venables and Ripley 2003), including only factors significant at a 5% confidence level. Each model was validated through a goodness-of-fit test and by examining the distribution of the model's residuals and their independence with respect to factors included in the model (Faraway, 2006).

For all selected models except number per mooring type (Table 3), the deviance explained by each factor was computed in order to identify the main factors influencing correspondent metrics in models.

For factors with more than two levels (year, weather and mooring type) displaying and a significant effect, multiple comparisons based on Tukey's Honest Significant Difference method (Tukey, 1977) were carried out to identify significantly different effects (at a 5% confidence level).

In the final step, we further examined the selection of mooring type (anchored, beached, permanent mooring and pontoon) as a function of boat type. This was possible in 2008 and 2013, for which mooring type was recorded for the boats observed. Associations between mooring type and boat type were shown through MCA. Site types were added as illustrative variables based on their relationship with the mooring type.

## 3 Results

### 3.1 Inter-annual changes in spatial distribution of boat numbers and density

The number of boats at islets dramatically increased over the decade, both inside or outside MPAs (Fig. 3 and Table 4). Mean numbers were higher inside MPA islets over the period as a whole, and between 2005 and 2013 their increase was 197% inside and 338% outside MPAs (Table 4).

The number of boats clearly emerged as higher at islets than at reefs, and higher inside than outside MPAs (Fig. 3). At islets, the ratio of the mean number of boats inside MPAs to outside MPAs was 2.5 in 2005, 1.3 in 2008 and 1.7 in 2013 (Table 4). In the case of reefs, differences were more striking, with a maximum of 8 times more boats inside MPAs than outside MPAs in 2013. These differences were even more marked in the case of boat density (Fig. 3).

For all years, motorboats were the main boat type observed at each site type. Indeed, except around reefs inside MPAs in 2008, where sailboats represented 60% of boat type, the proportion of observed motorboats for a given site type and year lay between 40% and 70% (Table 4). For each boat type, numbers were higher around islets and inside MPAs, with at least 60% observed around islets inside MPAs each year. The reverse was the case for dinghies, which were more numerous outside than inside MPA islets in 2008 and 2013. In addition, the proportion of dinghies increased more at islets outside MPAs (from 11% in 2005 to 22% in 2013) than at islets inside MPAs (from 7% in 2005 to 11% in 2013).

Over the course of specific years, boat numbers were also found to be more variable across trips (Fig. 3). Factors explaining this variability were investigated through GLM (see § 3.3 below).

### 3.2 Weather typology

The first two axes of the MCA explained 74 percent of the inertia of the dataset. The first factorial axis was mostly correlated with weather score, while the second axis was correlated with wind speed and direction. The HAC conducted on the factorial coordinates resulting from the MCA (with 2 factorial axes) generated three clusters that explain 44% of the overall variance dataset. These three clusters were described as follows: 1) sunny days with south-easterly winds of speed less than 10 knots (49 trips); 2) days with wind direction other that south-east, and cloudy days with south-easterly wind speed less than 10 knots (52 trips); and 3) days with south-easterly wind speed higher than 10 knots (17 trips).

### 3.3 The influence of temporal factors on boat numbers

All models considered (Table 3) were validated and significantly explained the data (Table 5). The models respectively explained 59% of the deviance for overall boat numbers, 52% for both motorboats and dinghies, 39% for sailboats, and 34% for jet-skis (Table 5). Day type, weather and season explained a large part of deviance in all models (Table 5). In addition, inter-annual variations were significant for all boat types (except sailboats) and overall (Tables 5 and 6). Boat numbers were found to significantly increase with the year (Table 6). The increase in the overall boat number was not constant over the period: 40% per year between 2005 and 2008, versus 19% per year between 2008 and 2013.

Increases in boat numbers were found to depend on day type (for all boat types except sailboats) and season (only for overall boat numbers) as shown by significant effects of interaction between year and day type, and year and season. Hence, boat numbers particularly increased over the years at weekends (Fig. 4): between 2005 and 2013, the overall boat number increased threefold at weekends and by 22% during weekdays.

The significant interaction of year and season for overall boat numbers (Table 5) corresponded to a larger increase during the warm season than during the cold season (Table 6): between 2005 and 2013, the overall boat number increased by 400% during the warm season and by only 136% during the cold season. This means that differences in boat numbers between weekdays and weekends on the one hand, and between the warm season and the cold season on the other, have become much larger in the course of the decade. As a consequence, exceptionally high boat numbers are likely to be more frequent (see § 3.4).

These changes are not identical for all boat types. Between 2005 and 2013, the mean number of boats increased by 20% for sailboats, 29% for motorboats, 48% for jet-skis and 95% for dinghies. As well as the increase in boat numbers, there was thus a change in the proportion of each boat type, with relatively more dinghies and jet-skis in 2013 than in 2005. While day type, weather and season displayed a significant effect on overall boat numbers, the effect of weather was significant only for motorboats and dinghies, while the effect of season was significant for all boat types except dinghies (Table 5). On the other hand, the number of boats differed according to day type for all boat types. Again, the significance of interactions between intra-annual temporal factors and the year factor also depended on boat type. For sailboats and motorboats, day type significantly influenced boat numbers in all years, but this difference has been significant for dinghies only since 2008, and for jet-skis since 2013 (Fig. 4).

### 3.4 Presence of boats in MPAs and occurrence of peaks in boat numbers

On average, the majority of boats were observed inside MPAs (61%), but this varied somewhat from one trip to another (overall standard error, 26.6) (Fig. 5).

Over the entire period, the 90% percentile was 89 boats observed per trip, but year-specific counterparts were found to strikingly increase over the three years, with 90% percentiles corresponding to 38, 77 and 162 boats observed per trip in 2005, 2008 and 2013, respectively, thereby indicating the occurrence of larger concentrations of boats with the passage of time.

The probability of occurrence of peak days, i.e. days where the number of boats observed exceeded the 90% percentile, was significantly explained by temporal factors (Table 7). In this model, the proportion of deviance explained ranged from 22% in year 2005 to a maximum of 57% in 2013.

Not surprisingly, the probability of peak occurrence was significantly influenced by day type in each year and overall years, with a much higher probability during weekends (Table 8). The year effect was significant (Table 7), with a strong increase in peak occurrence over the decade (Table 8), leading to a majority (75%) of trips with more than 89 boats in 2013 (Fig. 5). Yet over the entire period, day type explains more deviance than the year (21% versus 18%). This pattern was consistent over the three years (non-significant interaction between year and day type).

The influence of weather was significant only in 2008. Similarly, a strong influence of season was apparent in 2013, in relation to a larger number of peaks during the warm season (Table 7). Hence, in 2008 and 2013, the main factors explaining the probability of occurrence of peak numbers were environmental (weather and season), in relation to year-specific weather conditions.

Based on the year-specific definition of peaks, the proportion of boats inside MPAs during peak days was 69% in 2005, 59% in 2008 and 61% in 2013, showing that in each year, the majority of boats were concentrated in MPAs during peak days. Furthermore, similar proportions of boats inside MPAs were also found during non-peak days.

### 3.5 Evolution of mooring type

Both in 2008 or in 2013, most boats appeared to use anchors, followed by permanent moorings and beaching (Fig. 6).

The number of boats per mooring type appeared to differ between 2008 and 2013 (Fig 6). This was confirmed by model results, as the GLM model (last row in Table 3) was validated and significantly explained 61% of the deviance of the data. Consistently with results in § 3.2, every temporal factor had a significant effect on the number of boats per mooring type. Hence, this number was significantly explained by intra-annual factors (day type, season, weather), but also significantly increased with the year (at a 5% significance level). The mean number of boats per mooring type was 82% higher in 2013 than in 2008, 500% higher during weekends than weekdays, and 116% higher during the warm season than the cold season.

Boat numbers differed in the three years according to mooring type. In 2008, only the mean number of anchored boats and the mean number of boats at the pontoon significantly differed. In contrast, in 2013 the mean number of anchored boats was significantly higher than for any other mooring type. In 2008, 51% of observed boats were anchored, while in 2013 the figure was 72%. Thus the nine permanent moorings installed between 2008 and 2013 did not result in an increase in the number of moored boats (Fig. 6), with, on average, 27% of permanent moorings utilized in 2013. These differences in the use of mooring type between 2008 and 2013 were confirmed by the model with a significant interaction effect of year and mooring type (Fig. 6). Multiple comparison tests showed a significant increase in the number of anchored boats between 2008 and 2013, while there was no such increase for boats at permanent moorings, on the beach and at the pontoon.

### 3.6 Mooring use as a function of boat type

The first axis of the MCA conducted on the contingency table of boat type and mooring type (Fig. 7) explained 95% of the variance of the data. The first axis distinguishes dinghies, which were highly correlated with beached boats, from sailboats, which were strongly associated with permanent moorings. Jet-skis visited the pontoon and also beached. Motorboats were not associated with a particular mooring type. Likewise, anchoring was not associated with any particular boat type. The second axis was explained by the pontoon. This mooring type was the least observed mooring type because only one islet is equipped with a pontoon, which is used for temporary landing, mainly by jet-skis and motorboats. Reefs were unsurprisingly not correlated with beach and pontoon, since these mooring types do not exist at such sites.

Note that permanent moorings and the pontoon are found only in MPAs (Fig. 1). This presence is partly illustrated by the projection of site type on the factorial plan (Fig. 7), where islets inside MPA are respectively close to permanent moorings on the first axis, and the pontoon on the second axis. At islets, the proportion of users beaching is fairly high, respectively 15% in MPAs and 29% outside MPAs.

## 4 Discussion

### 4.1 Boat numbers sharply increased between 2005 and 2013

Based on a comprehensive dataset over a ten year period, our results clearly reveal and quantify a general increase in recreational boating activity in the Noumea area. This rise may be accounted for by a simultaneous increase in the number of registered boats and by demography. In New Caledonia, the proportion of people owning a boat for recreational purposes and subsistence fishing has been high for a long time (Jollit, 2010), and in the last decade the number of registered boats in the Noumea area has increased more than the number of inhabitants. The increase in the number of boats reveals that boating became more popular over this period. Several hypotheses may be put forward to explain this phenomenon, e.g. changes in the socio-economic context, such as improved amenities and infrastructure for boaters, an increase in people’s incomes, or the growing attractiveness of the natural assets of the islets and reefs (see Gray et al., 2010). This last possibility is consistent with the fact that over the years increasing numbers of boats have visited the Signal and Laregnere no-take reserves, where fish assemblages have been replenished through protection (Wantiez et al., 1997; Wantiez et al., 2004), and where amenities have been substantially developed in recent years. Such factors are consistent with the findings of Shivlani and Suman (2000) and Smallwood et al. (2012b), who show that recreational users are more likely to be found within MPAs. In addition to the benefits of protection, these two islets are located relatively close to Noumea city, and proximity is strong incentive for boaters. However, although each of these hypotheses is plausible, the present data are not intended to test any of them. Further investigations based on user interviews are currently under way. More generally, our results illustrate the consequences on recreational uses of the worldwide increase in coastal demography, as underlined, for example, by Duedall and Maul (2005). This increase is likely to be more of a concern for the management of coastal environment, especially when MPAs are located near large cities and potentially concentrate boaters, as in this study.

### 4.2 Inter-annual changes in the spatial distribution of boats

As a conservation instrument, MPAs generally aim at mitigating the anthropogenic impacts on the biodiversity they shelter. In MPAs, users' practices are generally regulated (e.g. extractive activities forbidden), whereas visitor numbers are often not restricted. In this paper, we found that the increase in boat numbers was mainly due to motorboats and dinghies. In addition, the increase mostly occurred at weekends, during the warmer season, and when the weather was sunny. This in turn resulted in more frequent peak counts, in particular in MPAs.

The numbers of motorboats, dinghies and to lesser extent jet-skis were the most sensitive to these short-term temporal factors. These findings are consistent with those of other studies, which have shown that day type, season and weather have an effect on the spatial distribution of recreational users (Widmer and Underwood, 2003; Smallwood, 2008; Martin and Hall-Harber, 2008; Dalton et al., 2010; Gray et al., 2010; Jollit et al., 2010; Smallwood et al., 2011; Smallwood et al., 2012a).

Consequently, managing recreational uses requires a better understanding of the distribution of recreational users in space and time (Eagles, 2002; Christie et al., 2003) and of their motivation and practices. This is particularly true in the light of their potential impact on habitats and species (see Davenport and Davenport (2006), and Whitfield and Becker (2014) for reviews).

### 4.3 Inter-annual changes result in increased occurrences of peak numbers

In the present study, we demonstrate, based on quantitative data, that the occurrence of peaks over the past decade in the lagoon near Noumea is explained by intra-annual factors. Indeed, although not displaying any temporal patterns in 2005, peak days were more likely to occur during fine weather in 2008 and in the warm season in 2013. These facts point to an intra-annual structuring of peak days and thus to a general change in boaters' planning strategy. However, it is not possible to conclude that this results from a change in every boater's planning strategy or only of those who have frequented these sites since 2008 or 2013.

Again, peak counts should be monitored carefully, because they may lead to more intense environmental impacts. In addition, from a social standpoint, concentration of users in small areas, as observed within MPAs in the Noumea area's lagoon, will inevitably result in overcrowding, affecting both the well-being and safety of recreational boaters (Tseng et al., 2009), even if up to now there is no published evidence of a relationship between the number of boats and the number of people expressing user satisfaction (Sutton, 2005). Moreover, Kuentzel and Heberlein (1992) and Navarro-Jurrado et al. (2013) underline that when faced by overcrowded events, recreational users may adopt a displacement strategy, either within or between sites. Thus the increase in both the number of boats during peak days and of the likelihood of peak days, as observed in the Noumea lagoon over the last decade, could lead to a change in the spatial distribution of recreational boaters.

### 4.4 Concomitant changes in mooring practices

The observed increase in the number of moored boats is obviously linked to an increase of boat traffic (Widmer and Underwood, 2004), which may have negative impact on users' safety (Miller and Pikora, 2008; McKnight et al., 2007) and satisfaction (Roman et al., 2007; Tseng et al., 2009) and can lead to conflicts among users. Noise level and wave action from traffic, especially where there is a high boat density like that observed around MPA islets, may affect user satisfaction, although this cannot be tested from the present data.

Connected with increase of boating activity, our results show that in the study area, mooring practices changed between 2008 and 2013. In particular, a larger number of boats were anchored in 2013 compared to 2008, whereas the number of boats beached, on permanent mooring buoys or at the pontoon did not significantly increase. This might be explained by the fact that anchoring is used by every type of boat. Unfortunately, this type of mooring entails severe impacts on habitat (Backhurst and Cole, 2000; Milazzo et al., 2002; Davenport and Davenport, 2006). Installing permanent mooring buoys is the main management response to this problem (Francour et al., 2006). Yet we found that the mooring buoys installed between 2008 and 2013 were not much utilized. This fact could be explained by users' preferences, needs and beliefs regarding mooring practices, all of which are major factors affecting the utilization of permanent mooring (Diedrich et al., 2013). Our results thus highlight the relevance of sustained information about permanent mooring utilization, and why using permanent mooring is important for protecting habitats. For example, in situ signage can encourage boaters to adopt good environmental practices (Martin et al., 2015). Because MPAs are regarded mainly as instruments for environmental protection by boaters (Heck et al., 2011), they offer a good opportunity to foster the acceptance of protection rules, and to make information provision more effective in the light of biodiversity conservation.

## 5 Conclusion

To summarize, in this study we demonstrate the sharp increase in the numbers of recreational boats in recent years. The increase has been more marked at weekends, during the warm season, and when weather conditions are appropriate; and it has resulted in more frequent concentrations of boaters inside the no-take reserves.

These results highlight substantial changes in boaters' practices. There are several hypotheses to explain these facts, and interviews with boaters are likely provide complementary information for assessing more precisely boater practices and motivations with a view to explaining these changes. Such work is currently in progress.

Irrespective of the causes underlying the observed spatial and temporal distribution of boaters, our results point to a growing source of disturbance for habitats and species particularly inside MPAs, the main goal of which is to protect biodiversity. In addition, boating practices were found to be relatively sensitive to weather conditions, and inter-annual changes suggest that boat numbers and peaks might become more erratic, under poorly predictable climatic conditions. As a consequence, recreational activities should be regularly monitored over time to allow managers to anticipate potential impacts through adaptive responses.

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## References

Agardy, T. (2000). Effects of fisheries on marine ecosystems: a conservationist's perspective. ICES Journal of Marine Science, 57(3), 761–765. http://doi.org/10.1006/jmsc.2000.0721

Alban, F., Appéré, G., & Boncoeur, J. (2008). Economic Analysis of Marine Protected Areas. A Literature Review. (p. 51).

Andrefouët, S., Torres-Pulliza, D., 2004. Atlas des récifs coralliens de Nouvelle Calédonie. IFRECOR Nouvelle Calédonie & IRD Nouméa. April 2004. 26pp. + 22 fig.

Ashton, P. G., & Chubb, M. (1972). A preliminary study for evaluating the capacity of waters for recreational boating. Water Resource Bulletin, 8(3), 571–577.

Backhurst, M. ., & Cole, R. . (2000). Biological impacts of boating at Kawau Island, north-eastern New Zealand. Journal of Environmental Management, 60(3), 239–251. http://doi.org/10.1006/jema.2000.0382

Balaguer, P., Diedrich, A., Sardá, R., Fuster, M., Cañellas, B., & Tintoré, J. (2011). Spatial analysis of recreational boating as a first key step for marine spatial planning in Mallorca (Balearic Islands, Spain). Ocean & Coastal Management, 54(3), 241–249. http://doi.org/10.1016/j.ocecoaman.2010.12.002

Balmford, A., Gravestock, P., Hockley, N., McClean, C. J., & Roberts, C. M. (2004). The worldwide costs of marine protected areas. Proceedings of the National Academy of Sciences of the United States of America, 101(26), 9694–9697. http://doi.org/10.1073/pnas.0403239101

Bejder, L., Samuels, A., Whitehead, H., Gales, N., Mann, J., Connor, R., … Krützen, M. (2006). Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. Conservation Biology : The Journal of the Society for Conservation Biology, 20(6), 1791–8. http://doi.org/10.1111/j.1523-1739.2006.00540.x

Browman, H. I., & Stergiou, K. I. (2004). Perspectives on ecosystem-based approaches to the management of marine resources. In Marine Ecology Progress Series (Vol. 274, pp. 271–272).

Brown, P., & Taylor, R. (1999). Effects of trampling by humans on animals inhabiting coralline algal turf in the rocky intertidal. Journal of Experimental Marine Biology and Ecology, 235(1), 45–53. http://doi.org/10.1016/S0022-0981(98)00186-5

Casu, D., Ceccherelli, G., Curini-Galletti, M., & Castelli, A. (2006). Human exclusion from rocky shores in a mediterranean marine protected area (MPA): an opportunity to investigate the effects of trampling. Marine Environmental Research, 62(1), 15–32. http://doi.org/10.1016/j.marenvres.2006.02.004

Chabanet, P., Adjeroud, M., Andréfouët, S., Bozec, Y.-M., Ferraris, J., Garcìa-Charton, J.-A., & Schrimm, M. (2005, November 15). Human-induced physical disturbances and their indicators on coral reef habitats: A multi-scale approach. Aquatic Living Resources. http://doi.org/10.1051/alr:2005028

Chabanet, P., Guillemot, N., & Kulbicki, M. (2010). Baseline study of the spatio-temporal patterns of reef fish assemblages prior to a major mining project in New Caledonia (South Pacific). Marine Pollution Bulletin, 61(7-12), 598–611. http://doi.org/10.1016/j.marpolbul.2010.06.032

Chaboud, C., Méral, P., & Andrianambinina, D. (2004). Le modèle vertueux de l'écotourisme : mythe ou réalité ? L'exemple d'Anakao et Ifaty-Mangily à Madagascar. Mondes en développement. http://doi.org/10.3917/med.125.0011

Christie, P., McCay, B. J., Miller, M. L., Lowe, C., White, A. T., Stoffle, R., & David L. Fluharty. (2003). Toward developing a complete understanding: a social science research agenda for marine protected areas. Fisheries, 28(12), 22–26.

Claudet, J., & Pelletier, D. (2004). Marine protected areas and artificial reefs: A review of the interactions between management and scientific studies. Aquatic Living Resources. http://doi.org/10.1051/alr:2004017

Codarin, A., Wysocki, L. E., Ladich, F., & Picciulin, M. (2009). Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). Marine Pollution Bulletin, 58(12), 1880–7. http://doi.org/10.1016/j.marpolbul.2009.07.011

Dalton, T., Thompson, R., & Jin, D. (2010). Mapping human dimensions in marine spatial planning and management: An example from Narragansett Bay, Rhode Island. Marine Policy, 34(2), 309–319. http://doi.org/10.1016/j.marpol.2009.08.001

Davenport, J., & Davenport, J. L. (2006). The impact of tourism and personal leisure transport on coastal environments: A review. Estuarine, Coastal and Shelf Science, 67(1-2), 280–292. http://doi.org/10.1016/j.ecss.2005.11.026

David, G., Leopold, M., Dumas, P. S., Ferraris, J., Herrenschmidt, J. B., & Fontenelle, G. (2010). Integrated coastal zone management perspectives to ensure the sustainability of coral reefs in New Caledonia. Marine Pollution Bulletin, 61(7-12), 323–34. http://doi.org/10.1016/j.marpolbul.2010.06.020

De Santo, E. M. (2013). Missing marine protected area (MPA) targets: How the push for quantity over quality undermines sustainability and social justice. Journal of Environmental Management, 124, 137–146. http://doi.org/10.1016/j.jenvman.2013.01.033

Diedrich, A., Terrados, J., Arroyo, N. L., & Balaguer, P. (2013). Modeling the influence of attitudes and beliefs on recreational boaters' use of buoys in the Balearic Islands. Ocean and Coastal Management, 78, 112–120. http://doi.org/10.1016/j.ocecoaman.2013.02.027

Duedall, I. W., & Maul, G. A. (2005). Demography of Coastal Populations. In Maurice L. Schwartz (Ed.), Encyclopedia of Coastal Science (pp. 368–374). Springer Netherlands. http://doi.org/10.1007/1-4020-3880-1_115

Eagles, P., McCool, S., & Haynes, C. (2002). Sustainable tourism in protected areas: Guidelines for planning and management. (Adrian Phillips, Ed.) (p. 183). IUCN, Gland, Switzerland, and Cambridge, UK, the United Nations Environment Programme and the World Tourism Organization. Retrieved from http://cmsdata.iucn.org/downloads/pag_008.pdf

Faraway, J. J. (2006). Extending the linear model with R: generalized linear, mixed effects and nonparametric regression models. (T. & F. Group, Ed.) (p. 301). Chapman & Hall/CRC.

Francour, P., Magréau, J. F., Mannoni, P. A., Cottalorda, J. M., & Gratiot. (2006). Management guide for Marine Protected Areas of the Mediterranean sea, Permanent Ecological Moorings (p. 68). Nice.

Glynn, P. W. (1994). State of coral reefs in the Galapagos Islands: Natural vs anthropogenic impacts. Marine Pollution Bulletin, 29(94), 131–140. http://doi.org/10.1016/0025-326X(94)90437-5

Gray, D. L., Canessa, R., Rollins, R., Keller, C. P., & Dearden, P. (2010). Incorporating recreational users into marine protected area planning: a study of recreational boating in British Columbia, Canada. Environmental Management, 46(2), 167–80. http://doi.org/10.1007/s00267-010-9479-1

Griffin, T., Moore, S., Crilley, G., Darcy, S., & Schweinsberg, S. (2010). Protected area management : collection and use of visitor data. Volume 1 : summary and recommendations National Library of Australia Cataloguing-in-Publication Entry (Vol. 1, p. 48).

Heatwole, C. A., & West, N. C. (1982). Recreational-Boating Patterns and Water-Surface Zoning. Geographical Review, 72, 304. http://doi.org/10.2307/214529

Heck, N., Dearden, P., & McDonald, A. (2011). Stakeholders' expectations towards a proposed marine protected area: A multi-criteria analysis of MPA performance criteria. Ocean and Coastal Management, 54(9), 687–695. http://doi.org/10.1016/j.ocecoaman.2011.07.003

Hodgson, A. J., & Marsh, H. (2007). Response of dugongs to boat traffic: The risk of disturbance and displacement. Journal of Experimental Marine Biology and Ecology, 340, 50–61. http://doi.org/10.1016/j.jembe.2006.08.006

ISEE, 2014. Evolution de la population entre 2004 et 2014. Institut de la statistique et des études économiques de Nouvelle-Calédonie. 1p. <http://www.isee.nc>.

Jollit, I. (2010). Spatialisation des activités humaines et aide à la décision pour une gestion durable des écosystèmes coralliens : la pêche plaisancière dans le lagon sud-ouest de la Nouvelle-Calédonie. Université de la Nouvelle-Calédonie.

Juhasz, A., Ho, E., Bender, E., & Fong, P. (2010). Does use of tropical beaches by tourists and island residents result in damage to fringing coral reefs? A case study in Moorea

French Polynesia. Marine Pollution Bulletin, 60(12), 2251–6. http://doi.org/10.1016/j.marpolbul.2010.08.011

Kay, A. M., & Liddle, M. J. (1989). Impact of human trampling in different zones of a coral reef flat. Environmental Management, 13(4), 509–520. http://doi.org/10.1007/BF01867685

Kenchington, R., 1990. Managing Marine Environments. Taylor & Francis, New York.

Kenchington, R. (1993). Tourism in coastal and marine environments—a recreational perspective. Ocean & Coastal Management. http://doi.org/10.1016/0964-5691(93)90073-8

Kuentzel, W., & Heberlein, T. (1992). Cognitive and behavioral adaptations to perceived crowding: A panel study of coping and displacement. Journal of Leisure Research, 24(4), 377–393. Retrieved from http://www.uvm.edu/rsenr/ai/kuentzel_heberlein.pdf

Leujak, W., & Ormond, R. F. G. (2008). Reef walking on Red Sea reef flats – Quantifying impacts and identifying motives. Ocean & Coastal Management, 51(11), 755–762. http://doi.org/10.1016/j.ocecoaman.2008.07.002

Lloret, J., Zaragoza, N., Caballero, D., & Riera, V. (2008). Impacts of recreational boating on the marine environment of Cap de Creus (Mediterranean Sea). Ocean and Coastal Management, 51, 749–754. http://doi.org/10.1016/j.ocecoaman.2008.07.001

Martin, C. L., Momtaz, S., Jordan, A., & Moltschaniwskyj, N. a. (2015). An assessment of the effectiveness of in-situ signage in multiple-use marine protected areas in providing information to different recreational users. Marine Policy, 56, 78–85. http://doi.org/10.1016/j.marpol.2015.03.002

Maynard, J. a, Anthony, K. R. N., Afatta, S., Dahl-Tacconi, N., & Hoegh-Guldberg, O. (2010). Making a model meaningful to coral reef managers in a developing nation: a case study of overfishing and rock anchoring in Indonesia. Conservation Biology : The Journal of the Society for Conservation Biology, 24(5), 1316–26. http://doi.org/10.1111/j.1523-1739.2010.01487.x

McKnight, a. J., Becker, W. W., Pettit, A. J., & McKnight, a. S. (2007). Human error in recreational boating. Accident Analysis and Prevention, 39, 398–405. http://doi.org/10.1016/j.aap.2006.09.004

Merchant, N. D., Pirotta, E., Barton, T. R., & Thompson, P. M. (2014). Monitoring ship noise to assess the impact of coastal developments on marine mammals. Marine Pollution Bulletin, 78(1-2), 85–95. http://doi.org/10.1016/j.marpolbul.2013.10.058

Milazzo, M., Chemello, R., Badalamenti, F., Camarda, R., & Riggio, S. (2002). The impact of human recreational activities in marine protected areas: What lessons should be learnt in the Mediterranean Sea. Marine Ecology 23 (. Suppl., 1, 280–290.

Milazzo, M., Badalamenti, F., Ceccherelli, G., & Chemello, R. (2004). Boat anchoring on Posidonia oceanica beds in a marine protected area (Italy, western Mediterranean): effect of anchor types in different anchoring stages. Journal of Experimental Marine Biology and Ecology, 299(1), 51–62. http://doi.org/10.1016/j.jembe.2003.09.003

Miller, J. R., & Pikora, T. J. (2008). Alcohol consumption among recreational boaters: Factors for intervention. Accident Analysis and Prevention, 40, 496–501. http://doi.org/10.1016/j.aap.2007.08.004

Monz, C. A., Cole, D. N., Leung, Y. F., & Marion, J. L. (2010). Sustaining visitor use in protected areas: Future opportunities in recreation ecology research based on the USA experience. Environmental Management, 45, 551–562. http://doi.org/10.1007/s00267-009-9406-5

Navarro Jurado, E., Damian, I. M., & Fernández-Morales, A. (2013). Carrying Capacity Model Applied in Coastal Destinations. Annals of Tourism Research, 43, 1–19. http://doi.org/10.1016/j.annals.2013.03.005

Parnell, P. E., Dayton, P. K., Fisher, R. a, Loarie, C. C., & Darrow, R. D. (2010). Spatial patterns of fishing effort off San Diego: Implications for zonal management and ecosystem function. Ecological Applications, 20(8), 2203–2222. http://doi.org/10.1890/09-1543.1

Pelletier, D., García-Charton, J. A., Ferraris, J., David, G., Thébaud, O., Letourneur, Y., … Galzin, R. (2005). Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: A multidisciplinary standpoint. Aquatic Living Resources, 18(August 2015), 15–33. http://doi.org/10.1051/alr:2005011

Pelletier, D. (2011). Indicators - Construction and validation. In J. Claudet (Ed.), Marine Protected Area: A multidisciplinary approach (pp. 247–289). Cambridge: Cambridge University Press.

Pomeroy, R. S., Watson, L. M., Parks, J. E., & Cid, G. A. (2005). How is your MPA doing? A methodology for evaluating the management effectiveness of marine protected areas. Ocean and Coastal Management, 48(7-8), 485–502. http://doi.org/10.1016/j.ocecoaman.2005.05.004

Preuss, B. (2012). Évaluation de scénarios de gestion des ressources du lagon Sud-ouest de la Nouvelle-Calédonie : Intégration des connaissances et modélisation spatialement explicite. Thèse de Doctorat, 400. http://doi.org/10.6098/2012NCAL0040

Rako, N., Fortuna, C. M., Holcer, D., Mackelworth, P., Nimak-Wood, M., Pleslić, G., … Picciulin, M. (2013). Leisure boating noise as a trigger for the displacement of the bottlenose dolphins of the Cres-Lošinj archipelago (northern Adriatic Sea, Croatia). Marine Pollution Bulletin, 68(1-2), 77–84. http://doi.org/10.1016/j.marpolbul.2012.12.019

Rodgers, K. S., & Cox, E. F. (2003). The effects of trampling on Hawaiian corals along a gradient of human use. Biological Conservation, 112, 383–389. http://doi.org/10.1016/S0006-3207(02)00336-1

Roman, G. S. J., Dearden, P., & Rollins, R. (2007). Application of zoning and “limits of acceptable change” to manage snorkelling tourism. Environmental Management, 39(6), 819–30. http://doi.org/10.1007/s00267-006-0145-6

Saphier, A. D., & Hoffmann, T. C. (2005). Forecasting models to quantify three anthropogenic stresses on coral reefs from marine recreation: anchor damage, diver contact and copper emission from antifouling paint. Marine Pollution Bulletin, 51(5-7), 590–8. http://doi.org/10.1016/j.marpolbul.2005.02.033

Shivlani, M. P., & Suman, D. O. (2000). Dive operator use patterns in the designated no-take zones of the Florida Keys National Marine Sanctuary (FKNMS). Environmental Management, 25, 647–659.

Sidman, C. F. ., & Fik, T. J. (2005). Modeling spatial patterns of recreational boaters: vessel, behavioural, and geographic considerations. Leisure Sciences, 27, 175–189. Retrieved from http://search.proquest.com/docview/17670355?accountid=27530

Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., ten Cate, C., & Popper, A. N. (2010). A noisy spring: the impact of globally rising underwater sound levels on fish. Trends in Ecology & Evolution, 25(7), 419–27. http://doi.org/10.1016/j.tree.2010.04.005

Smallwood, C. B., & Beckley, L. E. (2008). Benchmarking Recreational Boating Pressure in the Rottnest Island Reserve, Western Australia. Tourism in Marine Environments. http://doi.org/10.3727/154427308788714821

Smallwood, C. B., Beckley, L. E., Moore, S. a., & Kobryn, H. T. (2011). Assessing patterns of recreational use in large marine parks: A case study from Ningaloo Marine Park, Australia. Ocean and Coastal Management, 54(4), 330–340. http://doi.org/10.1016/j.ocecoaman.2010.11.007

Smallwood, C. B., & Beckley, L. E. (2012a). Spatial distribution and zoning compliance of recreational fishing in Ningaloo Marine Park, north-western Australia. Fisheries Research, 125-126, 40–50. http://doi.org/10.1016/j.fishres.2012.01.019

Smallwood, C. B., Beckley, L. E., & Moore, S. a. (2012b). Influence of Zoning and Habitats on the Spatial Distribution of Recreational Activities in a Multiple-Use Marine Park. Coastal Management, 40(4), 381–400. http://doi.org/10.1080/08920753.2012.692312

St. Martin, K., & Hall-Arber, M. (2008). The missing layer: Geo-technologies, communities, and implications for marine spatial planning. Marine Policy, 32, 779–786. http://doi.org/10.1016/j.marpol.2008.03.015

Sutton, S. G. (2005). Factors influencing boater satisfaction in australia's great barrier reef marine park. Tourism in Marine Environments, 2, 13–22. http://doi.org/10.3727/154427305774865778

Tseng, Y. P., Kyle, G. T., Shafer, C. S., Graefe, A. R., Bradle, T. a., & Schuett, M. a. (2009). Exploring the crowding-satisfaction relationship in recreational boating. Environmental Management, 43, 496–507. http://doi.org/10.1007/s00267-008-9249-5

Tukey, J. W. (1977). Exploratory Data Analysis. Reading, MA: Addison-Wesley.

Vallega, A. (2001). Urban waterfront facing integrated coastal management. Ocean and Coastal Management, 44, 379–410. http://doi.org/10.1016/S0964-5691(01)00056-4

Venables, W. N., & Ripley, B. D. (2003). Modern Applied Statistics With S. Technometrics. Springer-Verlag. http://doi.org/10.1198/tech.2003.s33

Walker, D. I., Lukatelich, R. J., Bastyan, G., & McComb, A. J. (1989). Effect of boat moorings on seagrass beds near Perth, Western Australia. Aquatic Botany, 36(1), 69–77. http://doi.org/10.1016/0304-3770(89)90092-2

Wantiez, L., Thollot, P., & Kulbicki, M. (1997). Effects of marine reserves on coral reef fish communities from five islands in New Caledonia. Coral Reefs, 16, 215–224. http://doi.org/10.1007/s003380050077

Wantiez, L., Garrigue, C., & Virly, S. (2004). 3- New Caledonia. In K. Pritchard & T. Wendy (Eds.), Status of coral reefs in the South West Pacific (Reuben Sul, p. 19). Suva, Fiji: University of the South Pacific.

Whitfield, a K., & Becker, A. (2014). Impacts of recreational motorboats on fishes: A review. Marine Pollution Bulletin, 83(1), 24–31. http://doi.org/10.1016/j.marpolbul.2014.03.055

Widmer, W. M., & Underwood, a. J. (2004). Factors affecting traffic and anchoring patterns of recreational boats in Sydney Harbour, Australia. Landscape and Urban Planning, 66(2004), 173–183. http://doi.org/10.1016/S0169-2046(03)00099-9

Wood, L. J., Fish, L., Laughren, J., & Pauly, D. (2008). Assessing progress towards global marine protection targets: shortfalls in information and action. Oryx. http://doi.org/10.1017/S003060530800046X

## Figure Legends

**Fig. 1.** Map of the lagoon, islets and reefs facing Noumea, Dumbea and Païta. Reefs and islets named and filled in grey are sites included in this study.

**Fig. 2.** Number of inhabitants per year in Noumea and nearby cities (in numbers/10. black bars) and number of registered boats (grey bars) between 2004 and 2014 (ISEE, 2014).

**Fig. 3.** Number (left) and density (nb/km$^2$) (right) of boats on reefs and islets as a function of year and protection status (inside MPA (grey) and outside MPA (white)). Bold bars indicate median value, limits of boxes indicates the first and third quartiles and tips of vertical bars correspond to the first and ninth deciles.

**Fig. 4.** Number of boats per boat type and overall boat types, per season and per year for weekend days (grey) and weekdays (white). Bold bars indicate median value, limits of boxes first and third quartiles and vertical bars first and ninth deciles.

**Fig. 5.** Overall number of boats per day trip as function of time. Stacked bars represent the number of boats per day trip inside MPAs (grey) and outside MPAs (black). The table below the plot reports for each year the number of peak days per day type and season based on the corresponding threshold: year-specific (dotted lines) and based on all observations (dashed line).

**Fig. 6.** Number of boats observed per day trip, per mooring type for 2008 (white) and 2013 (grey). Horizontal dashed lines represent the total number of permanent moorings for each year. The same letter under two contiguous boxplots indicates a significant difference between corresponding category combinations, based on the post-hoc test (Tukey) at the 5% significance level.

**Fig. 7.** Projection of boat type and mooring type variables on the factorial plan of the factorial correspondent analysis. Site types are projected on factorial plan as illustrative variable.

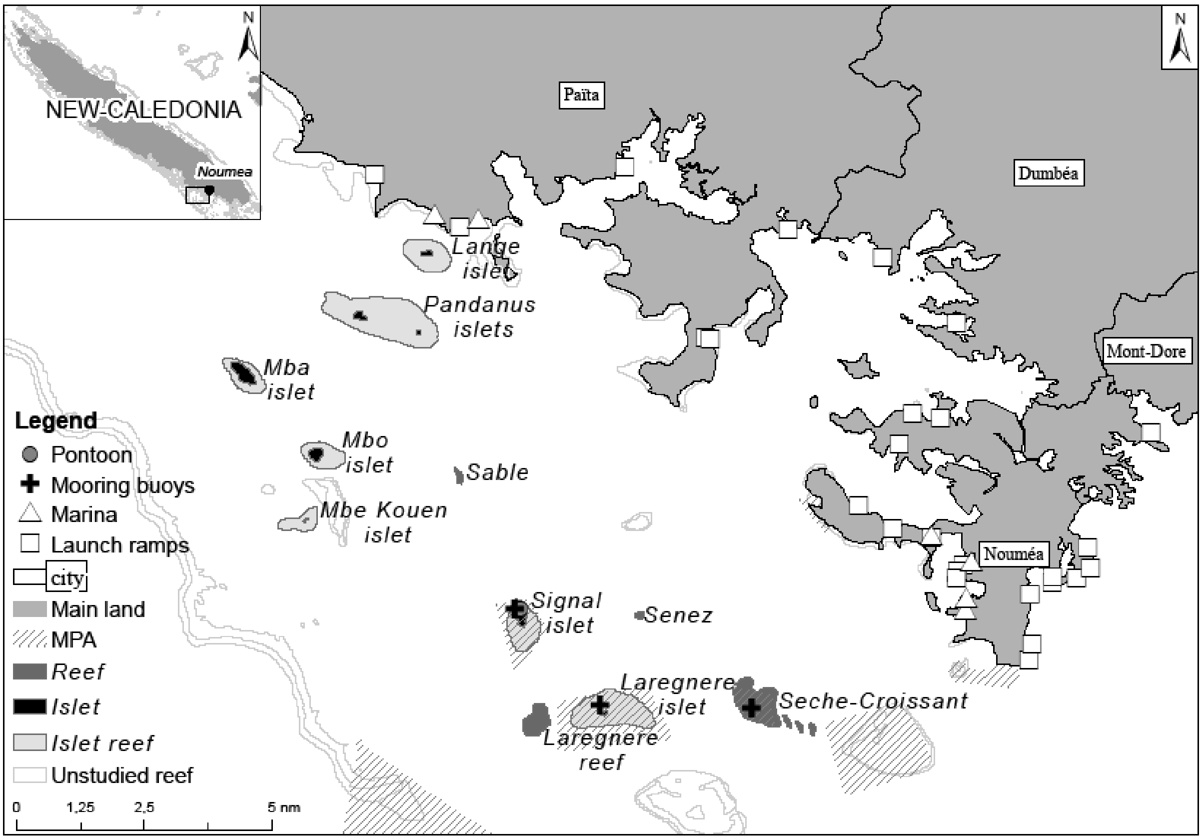


**Fig. 1.** Map of the lagoon, islets and reefs facing Noumea, Dumbea and Païta. Reefs and islets named and filled in grey are sites included in this study.

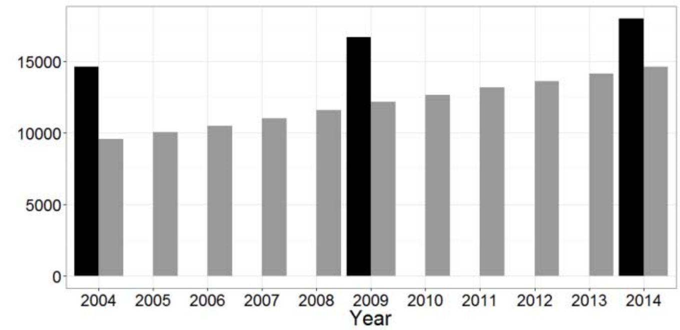


**Fig. 2.** Number of inhabitants per year in Noumea and nearby cities (in numbers/10. black bars) and number of registered boats (grey bars) between 2004 and 2014 (ISEE, 2014).

**Table 1**
Number of day trips per year, season and day type.

| Year | Warm season | | Cool season | | Total |
|---|---|---|---|---|---|
| | Weekend day | Weekday | Weekend day | Weekday | |
| 2005 | 12 | 12 | 11 | 8 | 43 |
| 2008 | 12 | 9 | 18 | 6 | 45 |
| 2013 | 6 | 7 | 10 | 7 | 30 |

**Table 2**
Number of sampling day trips per category of weather-related variables.

| Variables | Categories | Number of trips |
|---|---|---|
| Weather score | Sunny | 82 |
| | Cloudy or rainy | 36 |
| Wind speed | >10 knots | 94 |
| | <10 knots | 24 |
| Wind direction | SSW to ENE | 81 |
| | SW to NE | 37 |

**Table 3**
Metrics, data distribution and explanatory factors included in each model.

| Metrics | GLM distribution | Factors in complete model | Obs. Nb. |
|---|---|---|---|
| Number of boats per day trip per boat type | Negative binomial | day type / weather / season / year / year x day type / year x season | 118 per boat type |
| Odd of peak count in 2005 | Binomial | day type / weather / season | 43 |
| Odd of peak count in 2008 | | | 45 |
| Odd of peak count in 2013 | | | 30 |
| Odd of boat peak count all years | | day type / weather / season / year / year x day type / year x season | 118 |
| Number of boats per mooring type per day trip | Negative binomial | day type / weather / season / year / mooring type / year x day type / year x season / year x mooring type | 75 |

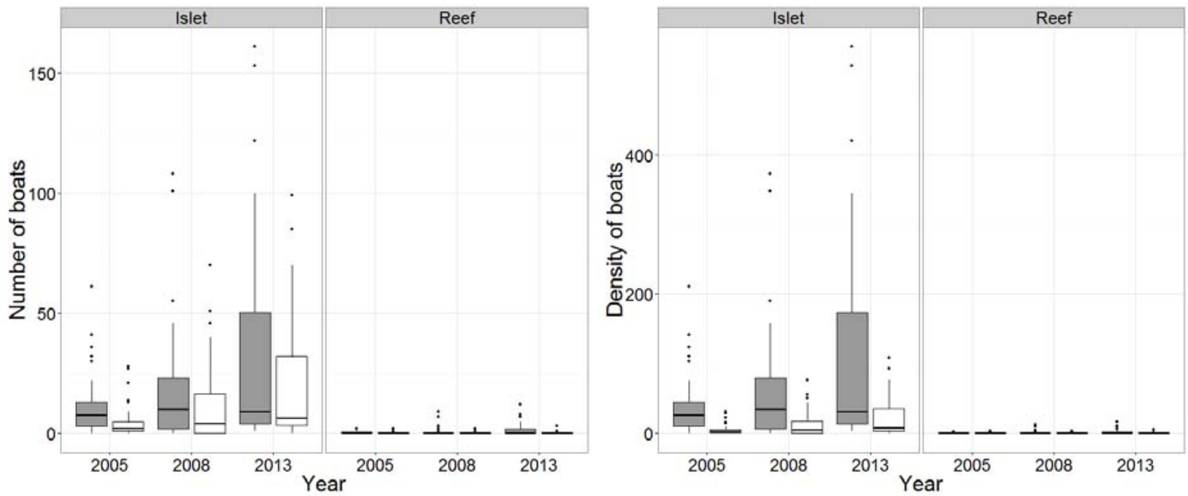


**Fig. 3.** Number (left) and density (nb/km$^2$) (right) of boats on reefs and islets as a function of year and protection status (inside MPA (grey) and outside MPA (white)). Bold bars indicate median value, limits of boxes indicates the first and third quartiles and tips of vertical bars correspond to the first and ninth deciles.

**Table 4**
Mean number (±variance) of boats per year, site type for all boat types and per boat type.

| | | Islets | | Reefs | |
|---|---|---|---|---|---|
| | | Inside MPA | Outside MPA | Inside MPA | Outside MPA |
| Overall | 2005 | 8.29 ±*1.25* | 3.38 ±*0.38* | 0.34 ±*0.01* | 0.24 ±*0.01* |
| | 2008 | 11.02 ±*3.36* | 8.75 ±*3.25* | 0.44 ±*0.02* | 0.15 ±*0* |
| | 2013 | 24.65 ±*13.51* | 14.81 ±*5.09* | 1.40 ±*0.12* | 0.18 ±*0.01* |
| Jet-ski | 2005 | 0.75 ±*0.08* | 0.04 ±*0* | 0 ±*0* | 0 ±*0* |
| | 2008 | 0.46 ±*0.02* | 0.42 ±*0.01* | 0.01 ±*0* | 0 ±*0* |
| | 2013 | 1.97 ±*0.22* | 0.55 ±*0.03* | 0.05 ±*0* | 0 ±*0* |
| Motor boat | 2005 | 4.01 ±*0.39* | 2.14 ±*0.16* | 0.27 ±*0.01* | 0.19 ±*0* |
| | 2008 | 5.36 ±*1.02* | 3.99 ±*0.71* | 0.16 ±*0* | 0.05 ±*0* |
| | 2013 | 13.98 ±*6.19* | 8.13 ±*2.36* | 0.76 ±*0.05* | 0.172±*0.01* |
| Dinghy | 2005 | 0.61 ±*0.03* | 0.38 ±*0.01* | 0.03 ±*0* | 0.04 ±*0* |
| | 2008 | 1.22 ±*0.10* | 2.90 ±*0.49* | 0.06 ±*0* | 0.06 ±*0* |
| | 2013 | 2.76 ±*0.35* | 3.38 ±*0.21* | 0.03 ±*0* | 0 ±*0* |
| Sail boat | 2005 | 2.91 ±*0.25* | 0.81 ±*0.05* | 0.04 ±*0* | 0.01±*0* |
| | 2008 | 3.98 ±*0.4* | 1.44 ±*0.12* | 0.21 ±*0.01* | 0.04 ±*0* |
| | 2013 | 5.94 ±*0.59* | 2.76 ±*0.13* | 0.55 ±*0.03* | 0.06 ±*0* |

**Table 5**
Proportion of deviance explained by each temporal factor or interaction of factors (rows) found to significantly influence boat numbers (overall or per boat type, column). The number of observations for each model was 118.

| Factors | Sailing boat | Motor boat | Dinghy | Jet-ski | overall |
|---|---|---|---|---|---|
| **Day type** | 37.7 | 28 | 11.3 | 9.5 | 31.3 |
| **Weather** | *ns* | 4.8 | 9.6 | *ns* | 3.8 |
| **Season** | 3.2 | 3.6 | *ns* | 8 | 2.4 |
| **Year** | 5.8 | 6.9 | 18.3 | 6.9 | 7.9 |
| **Year x Day type** | *ns* | 3.2 | 9.6 | 10.1 | 3.8 |
| **Year x Season** | *ns* | *ns* | *ns* | *ns* | 2.7 |
| **Deviance explained by model (%)** | 39 | 52 | 52 | 34 | 59 |

**Table 6**
Effects of explanatory factors on the mean number of boats per boat type (***: 0.1% significance level, **: 1% significance level, *: 5% significance level, .: 10% significance level, ns: non-significant). The metric decreases (↓) or increases (↑) with corresponding category relative to the reference category (zero effect). For example, downward arrows for day type or season indicate respectively a decrease of the number of boats during week days relative to weekend days and warm season relative to cold season.

| **Effects** | **Sailing boat** | **Motor boat** | **Dinghy** | **Jet-ski** | **overall** |
|---|---|---|---|---|---|
| | Direction of effect (significance level) | | | | |
| **Year** (2008) | ↑ | ↑ | ↑ (***) | ↑ | ↑ |
| **Year** (2013) | ↑ (***) | ↑ (***) | ↑(***) | ↑ (***) | ↑ (***) |
| **Day type** (Week day) | ↓ (***) | ↓ (***) | ↑ | ↓ | ↓ (***) |
| **Weather** (Cloudy or unusual wind direction) | *ns* | ↑ | ↑ | *ns* | ↑ |
| **Weather** (Sunny with low speed wind) | *ns* | ↑ (**) | ↑ (***) | *ns* | ↑ (**) |
| **Season** (Warm) | ↑ (*) | ↑ (**) | *ns* | ↑ (**) | ↓ |
| **Year** (2008) x **day type** (Week day) | *ns* | ↓ | ↓ (**) | ↓ (.) | ↓ |
| **Year** (2013) x **day type** (Week day) | *ns* | ↑ (**) | ↓ (***) | ↓ (***) | ↓ (***) |
| **Year** (2008) x **Season** (Warm) | *ns* | *ns* | *ns* | *ns* | ↑ (**) |
| **Year** (2013) x **Season** (Warm) | *ns* | *ns* | *ns* | *ns* | ↑ |
| Intercept | (***) | (***) | (*) | (*) | (***) |
| **Deviance explained by the model (%)** | 39 | 52 | 52 | 34 | 59 |

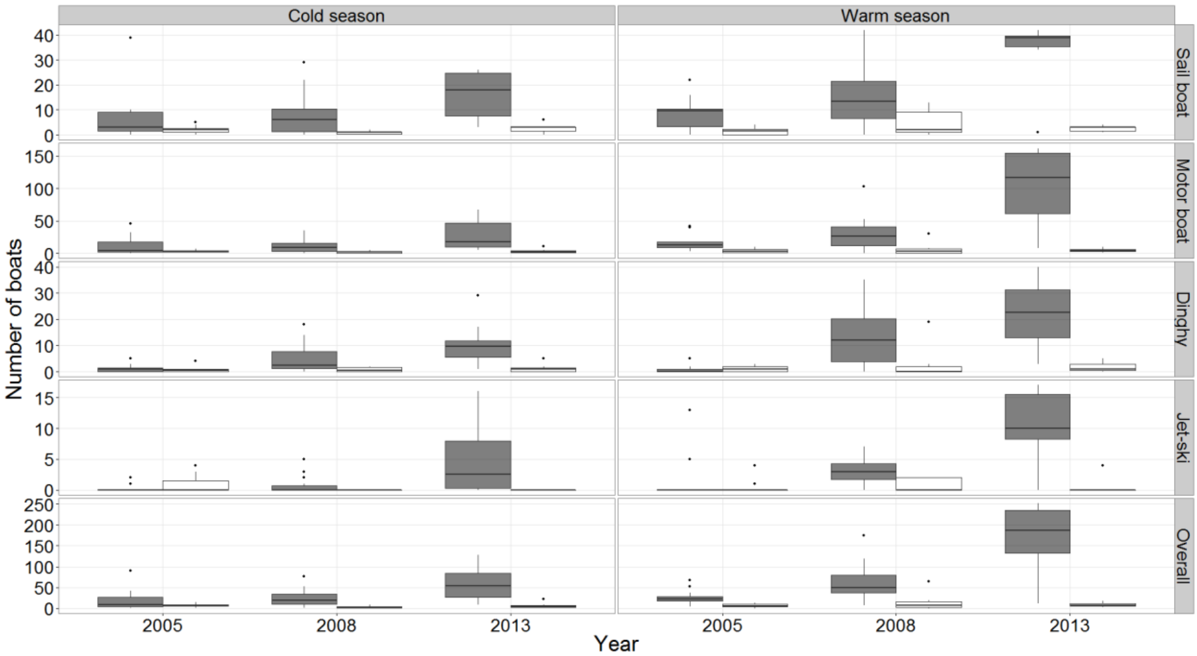


**Fig. 4.** Number of boats per boat type and overall boat types, per season and per year for weekend days (grey) and weekdays (white). Bold bars indicate median value, limits of boxes first and third quartiles and vertical bars first and ninth deciles.

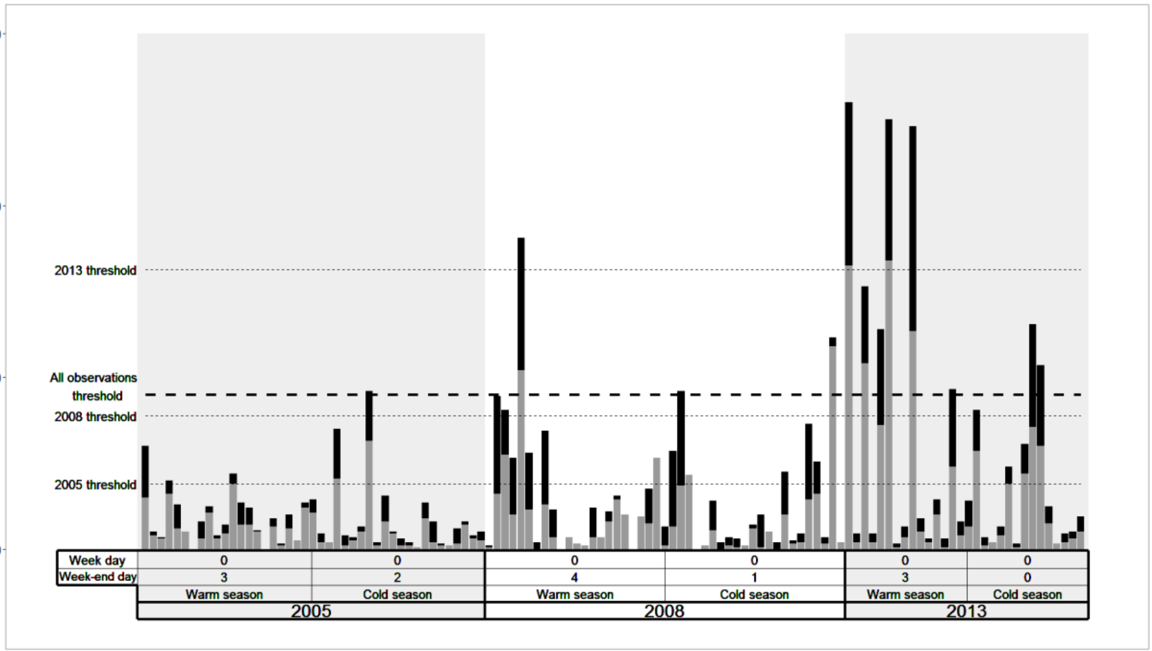


**Fig. 5.** Overall number of boats per day trip as function of time. Stacked bars represent the number of boats per day trip inside MPAs (grey) and outside MPAs (black). The table below the plot reports for each year the number of peak days per day type and season based on the corresponding threshold: year-specific (dotted lines) and based on all observations (dashed line).

**Table 7**
Relative proportion of deviance explained on the probability of the occurrence of peaks by each temporal factor and the model for each year and overall observations.

| **Parameters** | **Occurrence probability of peaks for** | | | |
|---|---|---|---|---|
| | 2005 | 2008 | 2013 | all obs. |
| **Day type** | 22 | 13 | 29 | 21 |
| **Weather** | *ns* | 21 | *ns* | *ns* |
| **Season** | *ns* | *ns* | 37 | *ns* |
| **Year** | *Terms not included in model* | | | 18 |
| **Year x Day type** | | | | *ns* |
| **Observation number** | 43 | 45 | 30 | 118 |
| **Deviance explained by model (%)** | 22 | 35 | 57 | 36 |

**Table 8**
Key variables affecting the occurrence probability of peak boat numbers (**: 1% significance level, *: 5% significance level, .: 10% significance level, ns: non-significant). The metric decrease (↓) or increase (↑) with corresponding category relative to intercept. For example, downward arrows for day type or season indicate respectively a decrease of the peak boat number during weekdays compared to weekend days and warm season compared to cold season.

| **Effects** | **Peak occurrence** | | | |
|---|---|---|---|---|
| | **2005** | **2008** | **2013** | **All obs.** |
| | Direction effect (significance level) | | | |
| **Year** (2008) | *Not included in model* | | | ↑ |
| **Year** (2013) | | | | ↑ (**) |
| **Day type** (Weekday) | ↓ | ↓ | ↓ | ↓ |
| **Weather** (Cloudy or unusual wind direction) | *ns* | ↓ | *ns* | *ns* |
| **Weather** (Sunny with low speed wind) | *ns* | ↑ | *ns* | *ns* |
| **Season** (Warm) | *ns* | *ns* | ↑ | *ns* |
| **Year** (2008) x **Day type** (Weekday) | *Not included in model* | | | *ns* |
| **Year** (2013) x **Day type** (Weekday) | | | | *ns* |
| Intercept | (*) | (.) | | (**) |
| **Deviance explained (%)** | 22 | 35 | 52 | 36 |

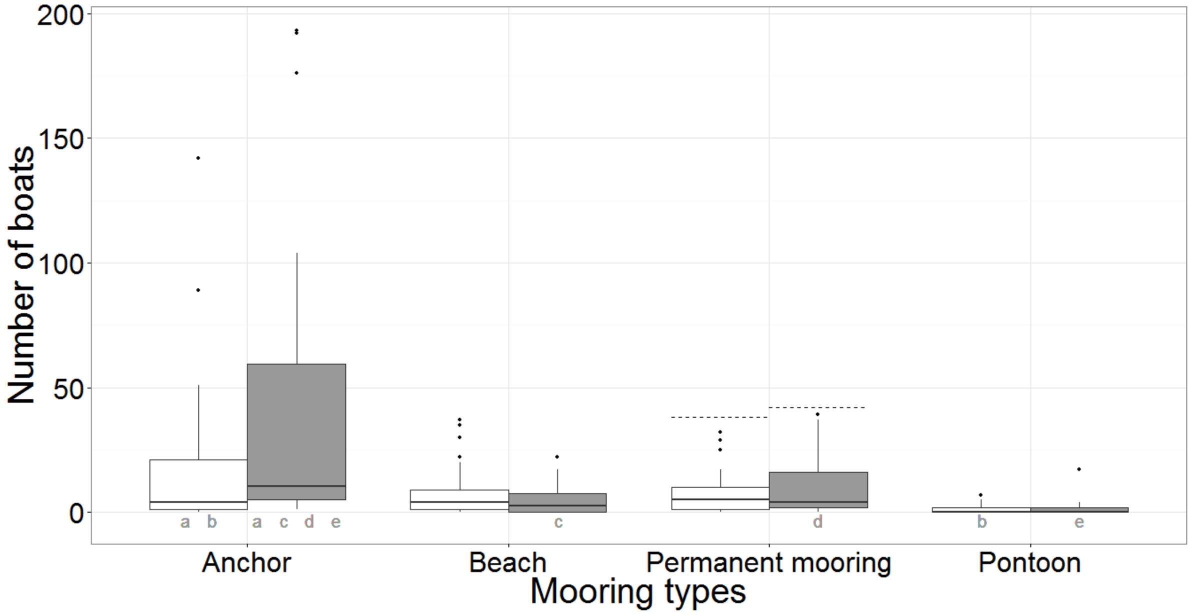


**Fig. 6.** Number of boats observed per day trip, per mooring type for 2008 (white) and 2013 (grey). Horizontal dashed lines represent the total number of permanent moorings for each year. The same letter under two contiguous boxplots indicates a significant difference between corresponding category combinations, based on the post-hoc test (Tukey) at the 5% significance level.

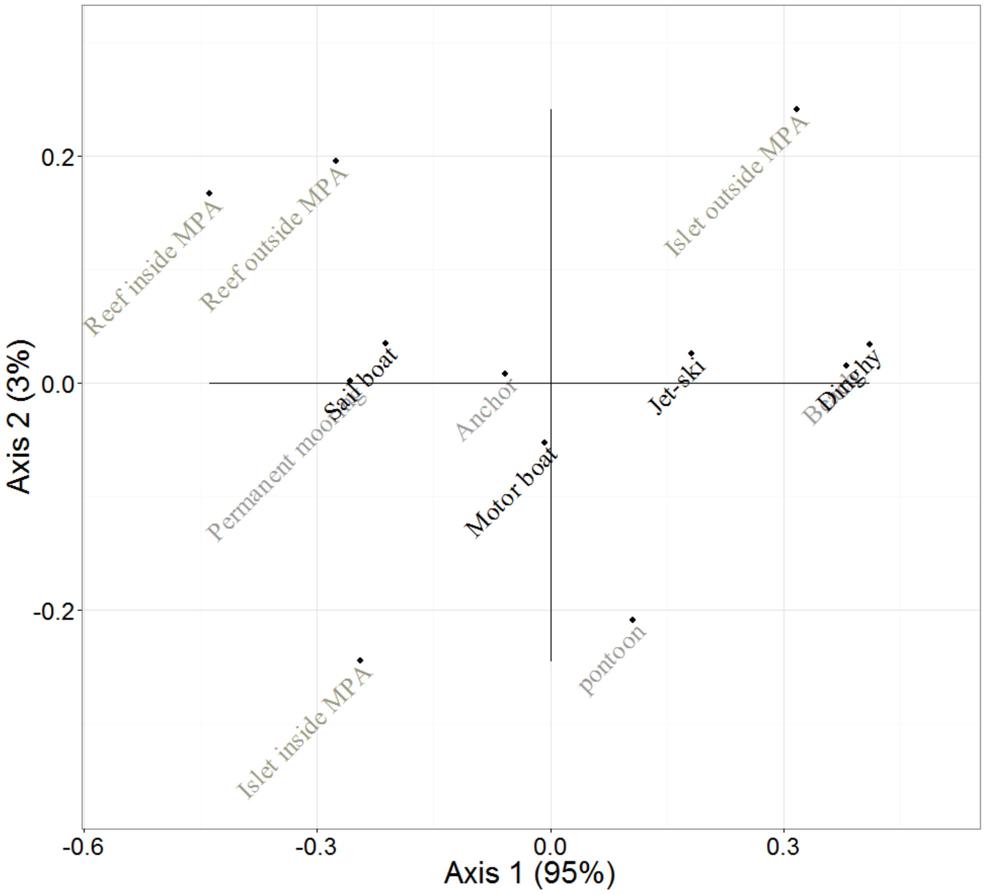


**Fig. 7.** Projection of boat type and mooring type variables on the factorial plan of the factorial correspondent analysis. Site types are projected on factorial plan as illustrative variable.