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ARTICLE

Harvesting the Beach Clam *Tivela mactroides*: Short- and Long-Term Dynamics

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Abstract
Small-scale fisheries are frequently overlooked for research and management, and their social and environmental impacts are often overlooked as well, preventing the implementation of appropriate actions for their sustainability. Additionally, the dynamics of beach clam fisheries and their importance for local communities are not well understood. A study on the population biology of the clam *Tivela mactroides* in Caraguatatuba Bay, southeastern Brazil, revealed intense harvesting of this resource by both residents and tourists. To assess the extent and dynamics of clamming, the number of harvesters was recorded during the course of the day in vacation and nonvacation periods throughout 2003–2005 and 2007–2008; the number of other beach users, weather conditions, and tide height were also recorded. The overall amount of clams harvested was estimated based on censuses of clammers and interviews to calculate the amount of clams harvested per collecting event. The intensity and dynamics of the harvesting activity varied on all the temporal scales evaluated. The estimated amount of clams harvested per year decreased from the first (24.6 kg/year) to the second (8.8 kg/year) group of sampling years, presumably due to clam mass-mortality events and smaller shell sizes in 2007–2008, although clam abundance increased enormously. Vacation periods (presence of tourists) influenced the number of harvesters and the daily dynamics of clamming activity, although this relationship was only evident during 2003–2004. The number of harvesters increased with the number of tourists, except in periods of very high tourist activity, when harvesting decreased. Clamming was more widespread during the day under high tourist activity but during nonvacation times was concentrated in morning low-tide periods. Weather had a partial influence on clamming, with harvesters absent only during intense rain occasions. The understanding of the dynamics of this *Tivela mactroides* fishery highlights key points for planning and implementing management measures, which will involve continuous monitoring of stocks, harvesting, and food safety.

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Beach clams are among the most important components of the intertidal macrofauna and are harvested throughout the world. This kind of harvesting may be conducted on a large commercial scale, especially in temperate regions, where clams tend to be larger and more commercially valuable. But most commonly, clamming occurs as a part of recreational activities and artisanal fisheries (MacLachlan et al. 1996; Dadon 2005; Defeo and MacLachlan 2005).

Consequently, most data on clam fisheries are derived from the temperate zones, mainly because landing statistics are more commonly reported and can be easily tracked for species of high commercial interest, whose yields are systematically computed in markets, fishing warehouses, or co-operatives (Caddy 1989). On the other hand, in contrast to the significant number of studies on most temperate sandy-beach bivalves, there is a lack of information on clam-harvesting issues, including the social aspects of clammers, for most clam species worldwide and this is even more pronounced for small-sized tropical species (Narchi 1976; Schaeffer-Novelli 1980; Viegas 1981; Paes 1989; Lima et al. 2000; Laudien et al. 2003; Hartill et al. 2005; Herrmann et al. 2009; Abrahão et al. 2010). This situation is often an important factor preventing the establishment of appropriate management strategies to allow sustainable use of these resources. The lack of data for some locations, however, should not be understood as reflecting lower abundance or importance of this resource, especially for local communities. Similarly, the need for appropriate management of clamming should not be underestimated, either to assure the maintenance of the clam populations or to assure food security.

A prominent example is *Tivela mactroides*, a common bivalve in moderately exposed sandy beaches, especially near river mouths, from São Paulo, Brazil, on the east coast of South America to the Caribbean Sea (McLachlan et al. 1996; Denadai et al. 2005). Little information on this species has been published, especially about harvesting. The only available estimates for *T. mactroides* consumption are from Venezuela, where the species was reported as highly abundant and was harvested for both recreational and commercial use (Prieto 1983; McLachlan et al. 1996). In 1992, the Venezuelan agency Servicio Autónomo de los Recursos Pesqueros y Acuícolas (SARPA) estimated that 354 tons of *T. mactroides* were collected in that country, which is likely an underestimate (McLachlan et al. 1996). No systematically collected temporal data set yet exists to allow for the continuous evaluation of a stock of this species or the extent of its harvesting.

During research on the biology of a tropical–subtropical population of *T. mactroides* in Caraguatatuba Bay, São Paulo State, southeastern Brazil (Denadai et al. 2005), intense harvesting was observed. The total amount of these clams harvested and consumed has not yet been estimated, so the extent of this informal activity is unknown. In the case of *T. mactroides* in Caraguatatuba Bay, this estimate is of interest for public health since the water quality in Caraguatatuba Bay is occasionally poor (CETESB 2014) and the consequent contamination of the clams may render them unfit for human consumption. Mass-mortality events have also been reported for this clam in the area (Turra et al. 2014). Although natural mass-mortality events are often reported for other clam populations (Dadon 2005; Aburto and Stotz 2013), the possible consequences for consumers of a large die-off cannot be overlooked.

Therefore, this area was chosen to evaluate the harvesting dynamics, over different temporal scales, based on censuses conducted year-round during two biennia (2003–2004 and 2007–2008). The different temporal scales encompassed (1) daylong assessments, (2) comparisons between vacation and nonvacation periods (which alter the human activity on sandy beaches), and (3) comparisons between the two biennia. Data for environmental factors (weather and tide height) and the number of beach users were included in order to evaluate their possible influence on the dynamics of this activity. The data from interviews of harvesters on the amount of clams collected allowed us to estimate the total amount of *T. mactroides* collected during the two periods. Since information on the population biology of *T. mactroides* is available for the same biennia (Turra et al. 2014), it was possible to assess the relationship between the stock and its harvesting.

METHODS

Study Area

Caraguatatuba Bay is located on the northern coast of the state of São Paulo and is limited to the south by Arpoar Point (23°43′25.3″S, 45°24′07.1″W) and to the north by Camaroeiro Point (23°37′41.1″S, 45°24′02.4″W) (Figure 1). The bay is bordered by a long sandy beach (about 16 km long) consisting of several named beaches (Enseada, Flecheiras, Porto Novo, Romance, Palmeiras, Pan-Brasil, Indaiá, Centro, and Camaroeiros) that are not separated by physical barriers. The beaches are subject to moderate wave energy, being sheltered by São Sebastião Island. Three main rivers (Juqueriquerê, Lagoa, and Santo Antônio) flow into the bay, transporting continental nutrients as well as organic pollution.

A 4-km stretch of beach between two rivers in the central-southern part of the bay (23°42′073″S, 45°25′447″W; 23°40′046″S, 45°25′490″W; Figure 1) was chosen as the study area because harvesting was concentrated there. No clamming activity was seen south of this area, possibly because that area is a tidal flat that requires walking longer distances and great effort to screen the sediment far from the water during low tides. North of the sampling area, the slope steepens and the short intertidal flat is less influenced by the rivers and is rapidly covered by rising tides.

FIGURE 1. Map of Caraguatatuba Bay showing the area where the censuses were conducted.

Sampling Procedures

Census and dynamics of harvesters.—The area was divided into 14 inline stations, each including central buildings or kiosks on the beach, which were used as observation points. At each of these, the number of people harvesting (harvesters or clammers) and other beach users were counted at six fixed daily times, 2 h apart (0700, 0900, 1100, 1300, 1500, and 1700 hours and occasionally, during the summer, also at 1900 hours), from an observation point to the limits of each counting station (midway between observation points). To exclude biases due to groups of clammers, whenever it was realized that a group of people was harvesting clams, the number of people composing each group was recorded and used in the subsequent analyses. This procedure was performed in two different biennia: on 40 d between May 2003 and January 2005 and on 56 d between March 2007 and April 2008. The sampling days were scheduled to cover a variety of periods, such as vacation or nonvacation, weekends and weekdays, and all seasons.

Weather (classified as clear, few clouds, partly cloudy, overcast, light rain, or rain) was recorded for each sampling time and observation point, and flood and ebb tide peaks (tide height, in meters) were recorded daily. Also, nonvacation periods (weekdays) were distinguished from vacation times (weekends, holidays, and summer holidays). These data were used in analyses of the temporal dynamics of harvesting.

Amount of clams harvested.—Interviews were conducted with harvesters working in the study area, who were approached and asked to answer the questions while collecting clams. The question of concern here was the amount of clams harvested per harvesting event, so whenever collectors were working in groups, only one person was interviewed. The interview was semistructured; because it may be difficult for collectors to state a precise amount per event, there was also an option with predetermined ranges of amounts (up to 1, over 1 up to 2, over 2 up to 5, over 5 up to 10, over 10 up to 20, and over 20 kg) for the interviewee to select. Other relevant questions, concerning socio-economic aspects of the harvesters and the fishery, were included and are being addressed in another context (A. Turra and colleagues, unpublished). The sampling intervals also covered different periods of the year (summer holidays, public holidays, weekends, and weekdays) and different daylight-hour intervals. The interviews were conducted from October 2003 through January 2005 (first biennium) and March 2007 through March 2008 (second biennium). From the information about the amount of clams harvested per harvesting event and the number of harvesters, the amount of clams harvested in the area was estimated.

Data Analysis

Census and dynamics of harvesters.—To assess the day-long panorama of the harvesting and the potential factors grouping harvesters on the beach, descriptive plots were constructed showing the percentage of the daily number of harvesters and other beach users in each 2-h interval. For this purpose, the data from all sampling points for the same 2-h interval and day were combined and converted to percentages. Raw daily values, and the respective tide and weather conditions, were added to the plots.

To assess how the two variables (number of harvesters and number of other beach users) were related to each other, the daily counts of harvesters were plotted and regressed as a function of the number of people on the beach. This was performed separately for each biennium. Since a clamming trip generally did not exceed 2 h (Turra and colleagues, unpublished) and recreational activity usually extended for a longer period, different units were used for each category in the regression test: the daily censuses of harvesters were based on the sum of all subareas and periods of a day, while the daily censuses of other beach users were based on a mean value across sampling points and periods of the day. This was obtained by calculating hourly mean values based on the sum of all sampling points and then obtaining a final daily mean value based on the sum of all time intervals.

To assess the influence of the clam stock on harvesting activity, the daily number of harvesters was also compared with the respective characterization of the clam population. For this purpose, data from the present study were plotted together with data on population dynamics and secondary production of *T. mactroides* (Turra et al. 2014). This produced a graph of the number and size of individual clams over time during similar study periods (2003–2004 and 2007–2008).

Since all analyses were performed separately for each biennium, comparisons between them were allowed at every step.

Estimate of the amount of T. mactroides *harvested*.—The next step attempted to estimate the total amount of *T.*

mactroides harvested per year over the sampling periods. The censuses of harvesters were combined with data from the interviews, which provided the mean amount of *T. mactroides* collected per harvesting event.

All reports on the amounts of clams collected per event (in kg) were classified into the predetermined options, retaining raw values when the amount reported exceeded 20 kg. A weighted average was then calculated: the number of times that a category was chosen (i.e., *n* people who gave that answer) was multiplied by its mean value (for each category, respectively: 0.5, 1.5, 3.5, 7.5, 15.0, and "mean raw value") and the sums of these values of all categories were added together and divided by the overall number of answers. The procedure was performed separately for each biennium.

Estimates were then made using the following steps:

1. The mean number of harvesters per day: based on the daily censuses, the mean number of harvesters per day was calculated for vacation and nonvacation periods for each sampling biennium. A factorial ANOVA or the equivalent nonparametric test was used to compare sampling years and vacation and nonvacation periods, followed by the respective post hoc test. Whenever no distinction between or among groups was detected, the group was treated as an overall mean for subsequent calculations.
2. The number of days within a period by year: the total numbers of vacation and nonvacation days within 1 year were calculated based on annual calendars. Occasional differences between the biennia were accounted for.
3. The number of harvesters within periods of a year (step 1 × step 2): the means obtained by step 1 (mean number of harvesters per day) were multiplied by the respective yearly number of days in each category (step 2) to estimate the overall number of harvesters in a year and in each period (vacation or nonvacation) of a year.
4. The mean number of harvesters per group: since only one person responded on behalf of a group during interviews, whenever the clammers were working in groups, the estimate of the amount of clams collected was based on harvesting events, i.e., on the groups rather than on individuals who were collecting clams, although some "groups" were composed of only a single individual. As described in step 1, the mean numbers of harvesters within groups were calculated and compared using a factorial ANOVA between sampling biennia and vacation or nonvacation periods. Whenever they differed significantly, different mean values were used in the subsequent procedures, and an overall mean value was used whenever they did not differ.
5. The number of harvesting events within the periods of a year (step 3/step 4): to convert the number of harvesters to the number of harvesting events, the number of harvesters within the periods of a year (step 3) divided by the mean number of harvesters per group (step 4) gave the number of harvesting events within the different periods of a year (vacation or nonvacation), again for each biennium separately.
6. The amount (kg) of clams collected per harvesting event: data from interviews were used to estimate the mean amount of clams collected per harvesting event for each biennium separately.
7. The amount (kg) of clams collected per period of the year (step 5 × step 6): finally, the extrapolation of data from the censuses of harvesters to the amount of clams collected per year consisted of multiplying the values from step 5 (number of harvesting events within a period) by the respective mean amount of clams collected per harvesting event (step 6) for each biennium separately.

RESULTS

Harvester Censuses and Dynamics

The daylong plots (Figures 2, 3) showed that when the number of other beach users increased, harvesting tended to be more equally distributed throughout the day, and at these times the harvesting activity tended to follow the daily peaks and troughs of the tourist concentration. In contrast, in nonvacation periods the time of day (early morning and late afternoon) and low tides were the main concentration factors. In these cases, most of the periods for which harvesting was not associated with ebb tides were during neap tides. Weather (except for heavy rain) had little influence on clamming activity whether tourists were present or not. These conditions were similar in both biennia, even from late April 2007 on, when there was a clear decrease in the number of harvesters (Figure 3). These results indicate that clam harvesting in Caraguatatuba Bay was influenced mainly by a social component (tourism), but when this component was not present, tide stage became important.

When the daily number of harvesters was tested as a function of the mean daily number of other users of the beach, dependence between the variables was observed in the first biennium, resulting in a negative quadratic function. Three main stages can be recognized in Figure 4 (left panel). When there were less than 400 people on the beach, a strong positive relationship between the variables was apparent, with small differences between the minimum and maximum number of harvesters. At around 400–850 beach users, the number of harvesters reached its peak but also very low numbers were observed, i.e., the number of harvesters varied widely. When the highest number of people were at the beach (over 850), the number of harvesters and the variation declined further. The numbers of harvesters and other users were square root transformed and applied to a linear regression, resulting in a significant ($P < 0.01$) linear function ($r^2 = 0.524$) of the number of harvesters according to the number of tourists, described as $y = 2.234 + 0.183x$.

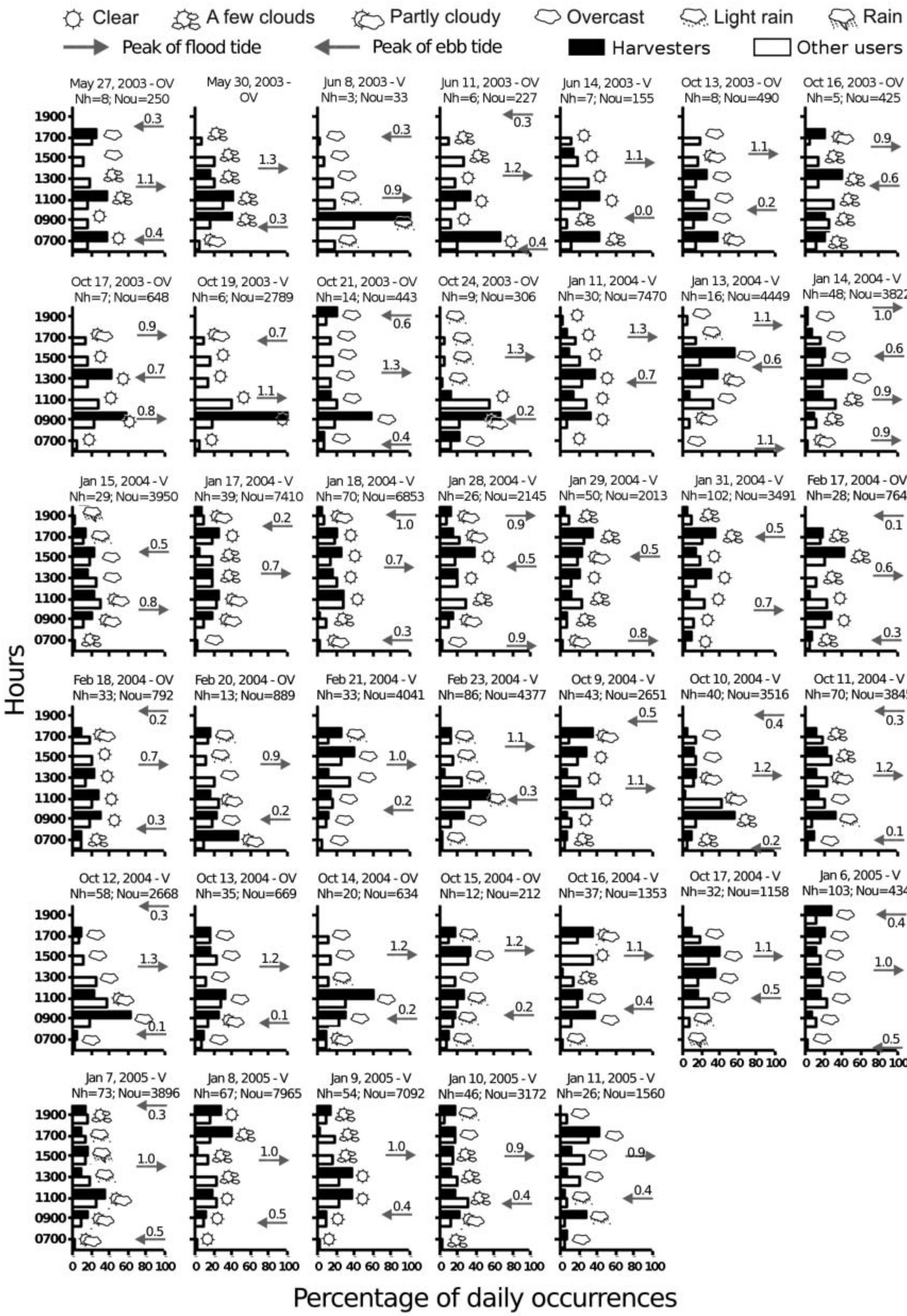

FIGURE 2. Percentage of the daily number of clam harvesters (Nh) and other beach users (Nou) in each 2-h interval from 0700–1700 hours (occasionally in summer to 1900 hours). Samples were taken in Caraguatatuba Bay on 40 d over the period from May 2003 through January 2005. Vacation days (V) were distinguished from nonvacation days (OV), and weather conditions (drawings) and tidal peaks (arrows) were recorded.

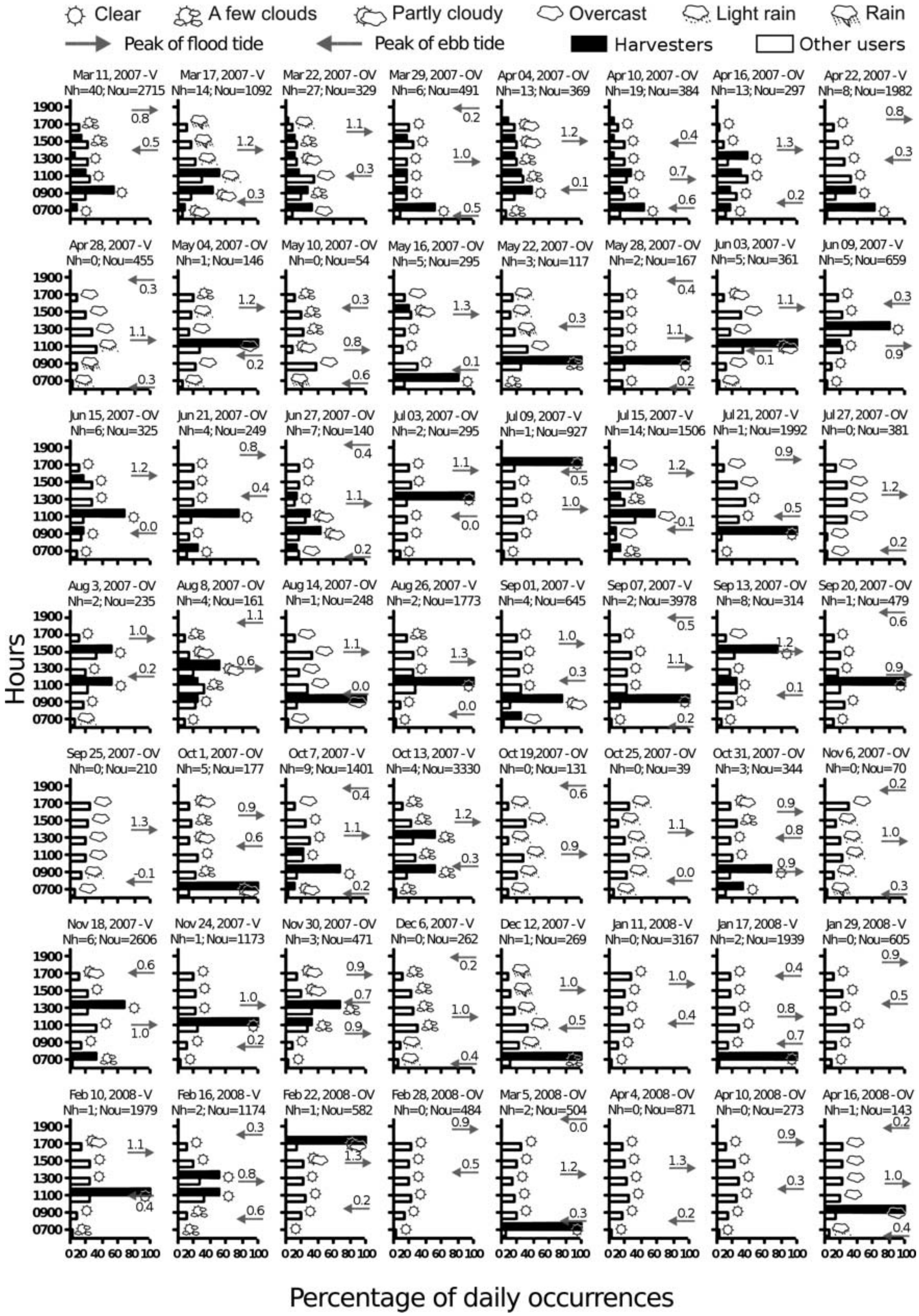

FIGURE 3. Percentage of the daily number of clam harvesters (Nh) and other beach users (Nou) in each 2-h interval from 0700–1700 hours. Samples were taken in Caraguatatuba Bay on 56 d over the period from March 2007 through April 2008. Vacation days (V) were distinguished from nonvacation days (OV), and weather conditions (drawings) and tidal peaks (arrows) were recorded.

For the second biennium, these variables showed no significant relationship, in spite of the model tested and although one outlier (corresponding to the first sampling day of the second biennium) was disregarded (Figure 4, right panel, point 1). Notably, due to the high concentration of dots on the left side of the graph (Figure 4, right panel), the number of harvesters was considerably lower, as was the number of other users in general. The numbers of harvesters and other users were log transformed [$\log_{10}(n + 1)$] and applied to a linear regression, and still no significant relationship between variables was identified ($P = 0.068$, $r^2 = 0.060$).

Another essential factor to consider is the characteristics of the *T. mactroides* population itself, here provided by the plot of the censuses together with data from Turra et al. (2014), with information on the means for both the number and size of the clams from this population (Figure 5). During the first biennium, the first census period (May–June 2003) began when the density of the clam population was among the lowest recorded, while the mean size of individual clams was intermediate (around 20 mm). The following census period of the first biennium (October 2003) was similar to the first with respect to the harvesting pattern, i.e., a relatively low number of harvesters and small differences between vacation and nonvacation periods. The abundance of clams, on the other hand, was about twice as high and their mean size about half that in the first period. The third census period (January–February 2004) was during the peak tourist season, including summer and Carnival holidays. The number of harvesters was extremely variable; the differences were associated with variations in tourism intensity, as described in the above analysis. By this time (January–February 2004), both the abundance and size of the clams had increased. These conditions remained quite similar in subsequent census periods of the first biennium, with respect to both harvesting intensity and clam population structure. The clam population structure may have had some influence on the harvesting intensity, since the abundance, and mostly size, were higher in periods when more harvesting events occurred. However, in this first period, clamming activity seemed to be more closely related to the concentration of people on the beach rather than to fluctuations in the clam population itself. In summation, the number of harvesters was positively associated with vacation periods, but these periods also showed wide variability in the number of harvesters during the first biennium.

In contrast, the characteristics of the clam population during the second biennium provided evidence that its features influenced the harvesting dynamics. During the beginning of the second biennium, the abundance was higher than in any period in the first biennium (Figure 5; note the scale differences in the middle panel between the left and right y-axes, which represent the two biennia, respectively), and the mean size of individual clams was also among the largest in the entire study. Notwithstanding, the related harvester censuses showed relatively high numbers and, as expected, the highest number of harvesters on a vacation day. These numbers are especially high, since these first censuses (March–April 2007) did not include peak tourist seasons. However, from May 2007 on, the abundance of clams increased dramatically, together with a sharp decrease in mean size. Subsequent censuses showed fewer harvesters, a situation that persisted through the end of the period. Even lower numbers of harvesters were recorded in the last censuses, which were conducted

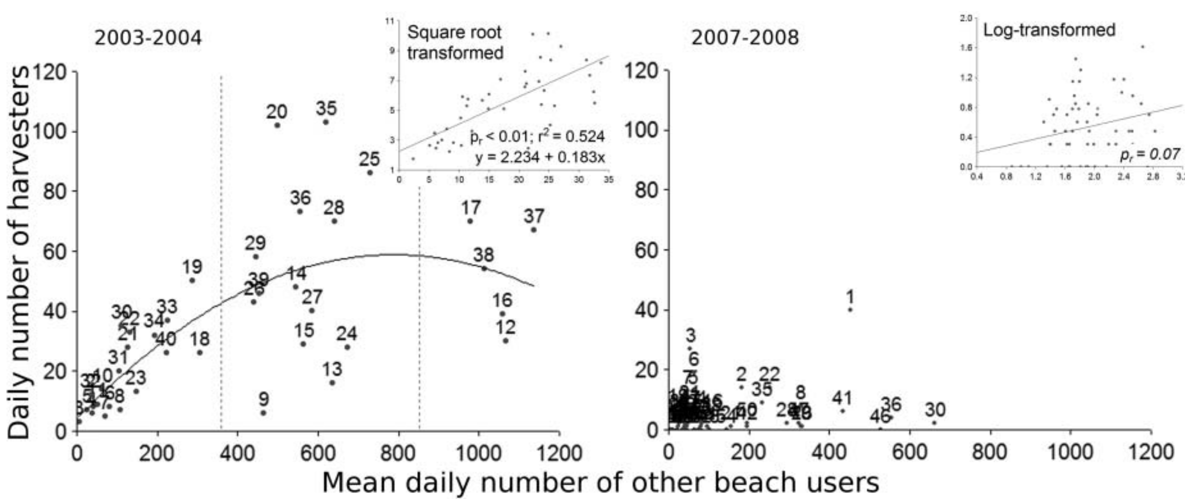

FIGURE 4. Relationship between the total daily number of clam harvesters of *Tivela mactroides* and the mean daily number of other people on the beach, based on counts at 2-h intervals. Plots are provided separately for the first (2003–2004; left panel) and the second (2007–2008; right panel) biennia assessed. The respective transformed data and the regression results are displayed in each panel at the upper right. The numbered replicates (numbered black dots) are equivalent to the sequence shown in Figures 2 (biennium 1) and 3 (biennium 2). The dashed lines in the left panel divide the graph into the three main stages identified.

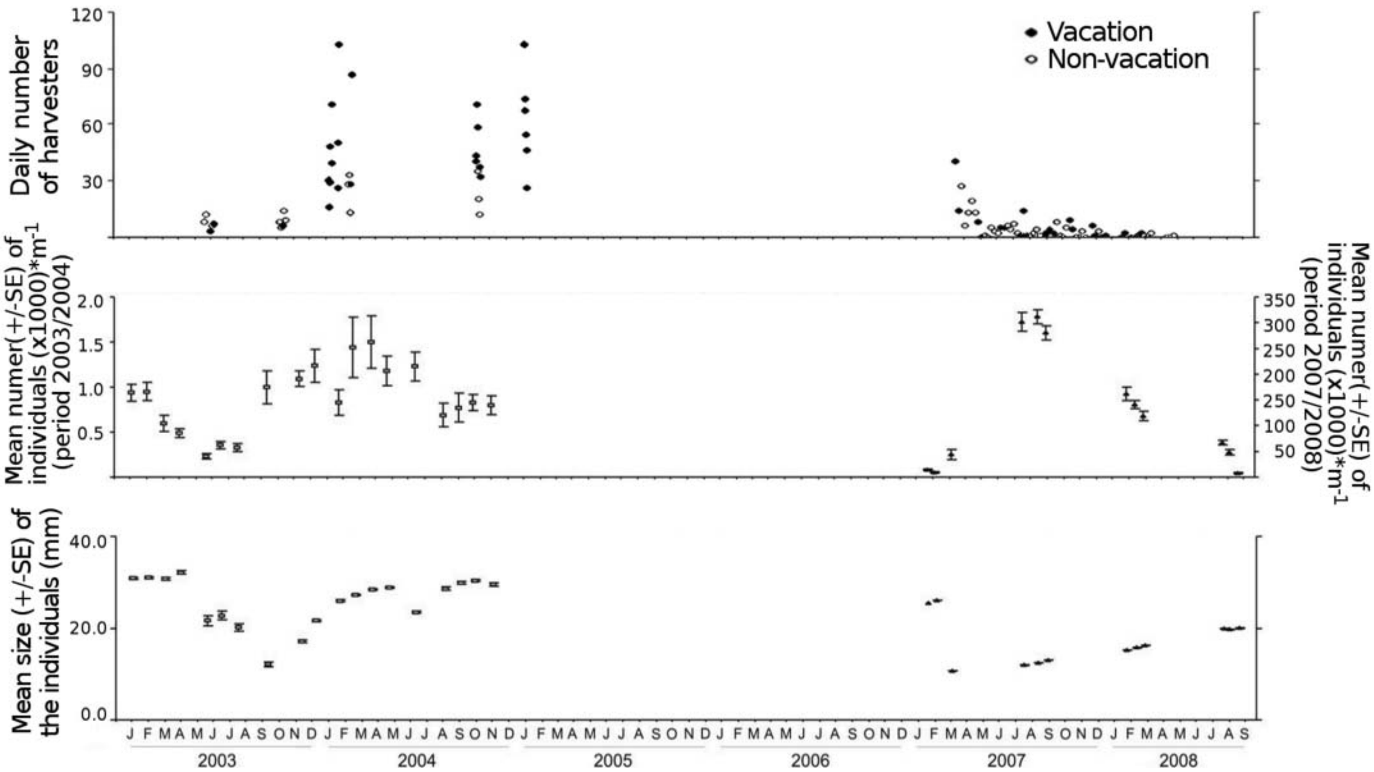

FIGURE 5. Temporal variation of the daily number of harvesters during vacation and nonvacation periods. Plots were obtained, together with data on temporal variation of *Tivela mactroides* density (individuals/m; unit obtained from the conversion of the number of individuals per strip transect of known length, 56 m, and width, 1 m) and size (mm), from Turra et al. (2014).

during vacation periods. During this period, the number of tourists was also considerably lower than the number in the first-biennium peak season (Figures 2, 3), possibly minimizing the wide variations in the number of harvesters observed during the first biennium. Therefore, the extreme conditions of the clam population (high abundance of small-sized individuals), and also the decrease in tourism activity (secondarily), seemed to strongly affect harvesting activity in the 2007–2008 biennium.

Estimate of the Amount of Clams Harvested

The mean number of harvesters differed significantly, both between the biennia and between vacation and nonvacation periods ($F_b = 80.83$, df = 1, $P < 0.01$; $F_s = 17.12$, df = 1, $P < 0.01$, respectively), with a significant interaction between factors ($F_i = 14.54$, df = 1, $P < 0.01$). The vacation period during the first biennium had the highest mean ± SD values (48.30 ± 26.95 harvesters), followed by the nonvacation condition (21.60 ± 19.60 harvesters), while the second period showed a significantly lower mean number of harvesters and no difference between the touristic conditions (5.30 ± 8.60 and 4.21 ± 6.01 harvesters, respectively; $P = 0.82$).

The pattern that was seen with the mean number of harvesters also occurred for the mean number of harvesters per group, with a significant difference between the two factors ($F_b = 58.23$, df = 1, $P < 0.01$; $F_s = 4.84$, df = 1, $P = 0.03$) and a significant interaction between factors ($F_i = 12.48$, df = 1, $P < 0.01$). Vacation periods in the first biennium showed the highest mean ± SD value (2.62 ± 0.62 harvesters/group), followed by nonvacation periods (1.91 ± 0.64 harvesters/group); the second period showed significantly lower values, with no difference between touristic conditions (1.41 ± 0.56 and 1.27 ± 0.41 harvesters/group, respectively; $P = 0.42$).

The responses to the interviews about the amount of clams (in kg) collected per harvesting event (Figure 6) were processed to determine a weighted average for each biennium. These averages were used to estimate the annual amount of clams collected in the study area. For the first biennium the average obtained was 4.74 kg, rising to 6.89 kg of clams collected in the second biennium (see Table 1 for a summary of the values used and the results).

There was a sharp difference between the estimates for the total amount of clams harvested in the study area in the two biennia. For the first biennium, this estimate was about 24.6 tons/year. Even with the higher estimated weight of clams

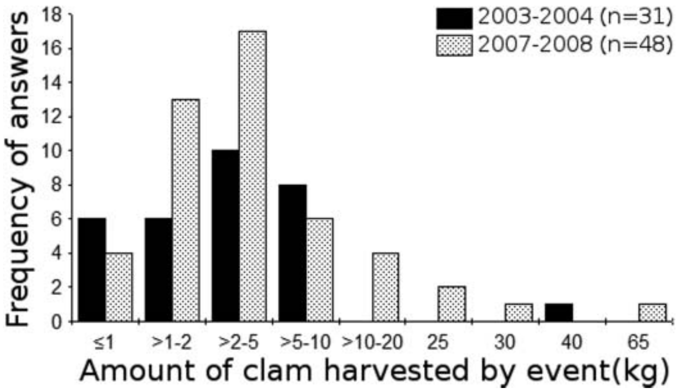

FIGURE 6. Frequency of responses to semistructured interviews of *Tivela mactroides* harvesters at Caraguatatuba Bay about the amount (in kg) of clams collected per harvesting event. Interviews were conducted from October 2003 through January 2005 (first biennium) and March 2007 through March 2008 (second biennium).

collected per harvesting event for the second biennium, the total amount of clams harvested for this period decreased by nearly one-third, to about 8.8 tons/year (Table 1).

DISCUSSION

Harvester Censuses and Dynamics

Collecting clams has a strong recreational appeal (MacLachlan et al. 1996; Griffiths et al. 2006; Dyson and Huppert 2010), and indeed, tourism considerably influenced the present results for harvesting intensity. However, as the routine of tourists differs substantially from that of local harvesters, the harvesting activity during peaks of tourism was perceptibly more diffused during the day, regardless of tide stage and weather conditions. Also, the reasons why tourists collect clams are very likely to differ because they are more likely to do it as a leisure activity and rarely depend on this resource or customarily consume clams. Local harvesters may collect clams for nearly opposite reasons, i.e., subsistence or economic reasons.

Taking into account the periods of low tourism activity, tide was a main component driving more intense harvesting, which tended to be concentrated during low tides. The concentration of clammers was uncorrelated with tide height only during neap-tide periods, when differences between low and high tides are minimal and apparently were not sufficiently different to affect the harvesting activity. Because the harvesters in this situation are much more likely to be local residents and frequent clammers, the results reflect more familiarity with the factors influencing the activity. Weather, except for heavy rain, did not seem to have a strong influence on harvesting and was the environmental condition that least affected this activity. This condition seems quite natural: for tourists it would be expected that only heavy rain would inhibit their leisure activities and, similarly, resident harvesters would prefer to wait for more favorable conditions. They might also be expected to avoid periods of more intense sunshine, but as these conditions may last for long periods, waiting may not be feasible.

The close relationship between harvesting and tourism was evident, showing not only that harvesting activity increases with increasing tourism but also that this concomitant increase has a limit. Clamming activity might have a snowball effect with respect to the presence of tourists: even tourists who have never collected a clam before are attracted by the activity when they see it being done and feel comfortable eating the clams because the local people do it. The more people collect clams, the more the activity is noticed by other tourists, and so on. After a given point, however, the number of tourists comes to be negatively correlated with the number of harvesters. Following the previous argument, if local harvesters cease their activity during periods of overcrowding, tourists would be less likely to collect clams, leading to the reverse effect. That is likely to happen because local harvesters will exploit the touristic activity as an informal source of revenue, a more profitable activity than clam harvesting during vacation periods. Another contributing factor may be that peak-season tourists, who are mainly day-trippers, usually have a different profile than those who visit the beach more frequently. The latter group would have more time available for different activities and more facilities in which to prepare their own meals.

The different results found in the second biennium can be attributed to the low number of harvesters and the considerably fewer tourists observed but also to the smaller size of the clams. It would be interesting to have data on the fluctuations in the number of tourists over time for the municipality, but unfortunately this information is not available for the study period. This could indicate whether the decrease in visitation was limited to the bay or was representative for the municipality as a whole. In any event, the extremely high abundance of clams in this period and location led to mass-mortality events of *T. mactroides*, most likely due to density-dependent processes (Turra et al. 2014), which may have been the main factor preventing visitation. In addition to the consequent foul odor and unpleasant sight, it is practically unavoidable to question why the mortality occurred and to be afraid to eat the clams (Figure 7). Even though high variability and density-dependent processes are normal features of clam populations (Dadon 2005; Aburto and Stotz 2013; Turra et al. 2014), Caraguatatuba Bay is an urban area that is subject to oil spills and discharges of industrial, domestic, and agricultural effluents. Factors that could cause or contribute to mass mortalities include ocean storms, excessive algal mats, parasite proliferation, and also contamination from oil spills (Araújo 2001; Jorge 2003; Dunham et al. 2007).

In summary, the mass-mortality events had a strong effect on the harvesting dynamics. During the first biennium, the relatively constant and moderate abundance and size of individual clams provided suitable conditions for harvesting. Wide fluctuations in the number of harvesters were hypothesized to

TABLE 1. Compiled data and schematic calculation of the estimated amount of *Tivela mactroides* harvested per year in Caraguatatuba Bay. Censuses of harvesters were conducted in two biennia, 2003–2004 and 2007–2008, distinguishing vacation (V) from nonvacation periods (N). For each period, the following variables were measured or calculated: the mean number of harvesters per day (A), total number of vacation or nonvacation days in a year (B), mean number of people per group (C), mean number of harvesting events per day (D), and mean amount of clams collected per harvesting event (E). A specific mean was calculated within each period (Specific), but a common mean value was used for periods that showed no statistical differences, so the values that were actually used are also shown (Used). The variables that were used in the final estimates are shown in bold italics. The steps of the calculations are shown with the column title, where applicable.

		(A) Mean number of harvesters/day			(C) Mean number of people/group		(D) Number of harvesting events/day (= A/C)			Estimate of clams harvested (kg/year) (= B·D·E)	
Biennium	Period	Specific	Used	(B) Number of days in a year	Specific	Used	Specific	Used	(E) Mean amount collected (kg)	Partial	Annual
1 (2003–2004)	V	48.30	***48.30***	***150***	2.62	***2.62***	18.43	***18.43***	***4.74***	13,107	24,632
	N	21.60	***21.60***	***215***	1.91	***1.91***	11.31	***11.31***		11,525	
2 (2007–2008)	V	5.30	***4.66***	***152***	1.41	***1.33***	3.98	***3.50***	***6.89***	3,669	8,811
	N	4.21	***4.66***	***213***	1.27	***1.33***	3.42	***3.50***		5,142	

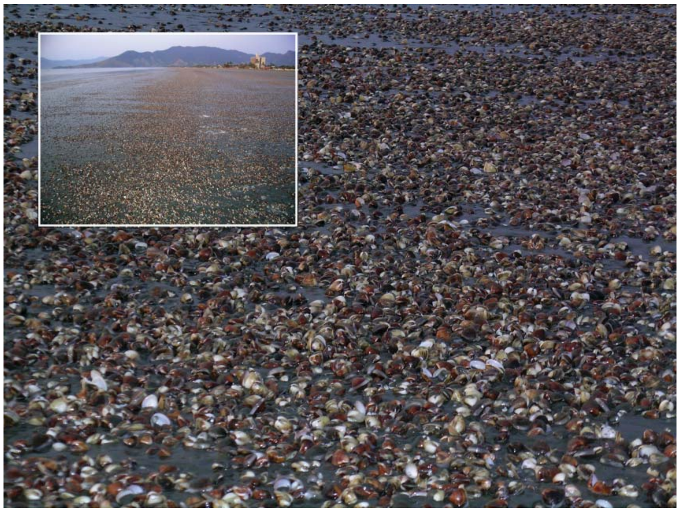

FIGURE 7. *Tivela mactroides* individuals covering the beach in Caraguatatuba Bay during a series of mass-mortality events in 2007 and 2008. On the day of the photograph, this abundance was consistent alongshore and across shore (detail).

be due to changes in tourism intensity, but probably the increasing harvesting activity was related to the increased abundance and size of the clams, characterizing it as an opportunistic activity. At the beginning of sampling in the second biennium, the abundance and size of clams were still high. The number of harvesters was correspondingly high, even for the equivalent period in the first biennium. However, despite the subsequent astonishing increase in the abundance of clams, the number of harvesters decreased considerably. This change may be related to the noticeable decrease in the size of the clams, making them unattractive for harvesting. Furthermore, these factors (unusually high density and small-sized individuals) led to mass-mortality events (Turra et al. 2014), which probably deterred tourism and further harvesting.

Estimate of the Amount of Clams Harvested

The demand for a resource is a key factor for environmental management. In the case of clams, if these filter feeders are exposed to pollutants they are very likely to transmit the contamination to their consumers. Closures of clam fisheries are common after blooms of toxic algae (Dyson and Huppert 2010; Chadsey et al. 2012), and Chen (1997) reported, following an instance of arsenic poisoning, that even consuming small amounts of clams exceeded the allowed limits. Data on *T. mactroides* revealed contamination by *Escherichia coli, Staphylococcus aureus, Vibrio cholerae* and *Salmonella* sp. in Caraguatatuba Bay, which raises concerns regarding clam consumption (M. R. Denadai and colleagues, unpublished).

In Caraguatatuba Bay, the historical lack of reports about the exploitation of *T. mactroides* leads to underestimation of this activity. For example, according to some informal reports, restaurants from the city of São Paulo occasionally order large amounts of *T. mactroides*. The present estimated amount of clams harvested reached almost 25 tons/year, which is not negligible. Although the larger clams in temperate zones tend to have much greater economic value (MacLachlan et al. 1996), some examples from tropical regions illustrate the significance of the present data. Murray-Jones and Steffe (2000) estimated that for a commercially exploited species on a 32-km-long beach in Australia (Caraguatatuba is 16 km long and the study area where the activity is concentrated was 4 km long), 46.5 tons/year was taken by recreational harvesters. On the Eastern Cape of South Africa, the sustainable amount of the clam *Donax serra* harvested for commercial exploitation was estimated at 100 tons/year (Sims-Castley and Hosking 2003).

Given the high abundance of *T. mactroides* in Caraguatatuba Bay, the current level of artisanal or recreational harvesting does not seem to be harming the clam population. This harvesting activity has probably been conducted for decades without damaging the resource, but changes in harvesting intensity and demand over time, as well as other causes of mortality (mass mortality and predation), may have affected clam abundance. An increase in recreational clammers, who tend to have few or no concerns about a minimum size for harvesting (Murray-Jones and Steffe 2000), may compromise not only the clam population but also the entire intertidal community (Dadon 2005).

The disturbance in the clam population that occurred in the second biennium of the study provided an opportunity to assess how the harvesters behaved in these circumstances. The enormous number of clams present did not encourage more people to harvest them; on the contrary, the number of harvesters decreased nearly tenfold. However, people who were still collecting the clams were possibly encouraged by their availability given the increase in the average amount collected per harvesting event mentioned in the interviews, an amount that increased from 4.74 to 6.89 kg.

Management Considerations

The enormous variability in the clam population abundance, the lack of concern and assessment about harvesting numbers, and underestimates of clam consumption due to lack of commercial sales in small-scale fisheries have led to a dearth of management efforts and of integration between policy makers and resource users (Murray-Jones and Steffe 2000; Castilla and Defeo 2001; Hartill et al. 2005; Wiber et al. 2010; Aburto and Stotz 2013). Lack of information and control measures may lead to dramatic consequences for the clam stocks, intertidal benthic community, organisms that depend on clams as a food source, and even social, economic, and cultural aspects of local and traditional communities.

Exploited beach clams generally burrow near the sediment surface in the intertidal zone of sandy beaches. They are easily harvested without the need of boats or special equipment, using only hands, feet, or in some cases, very simple tools. Access to sandy beaches is normally unrestricted, and there are no physical or economic barriers to harvesting resources from these environments. In this situation, one possible way to control indiscriminate harvesting would be based on a comanagement strategy supported by biological and social data on the activity. Castilla and Defeo (2001) recommended cooperative management efforts among fishermen, scientists, and managers to regulate the use of beach shellfisheries. Systematic data collection on stocks and harvesting activity is important to provide for sustainable use by local fishing communities. Studies in South America have already identified some local populations of *T. mactroides* that are close to extinction due to uncontrolled harvesting and that have not recovered after long-term closures (Ortega et al. 2012), which exemplifies the risks of neglecting the management of harvesting activity.

Since coastal environments are threatened by a variety of factors, from waste dumping to climate change, that require complex and long-term measures, macrofauna structure and stocks of beach shellfish may also be affected to some extent. However, overexploitation of this resource is one of the factors that can be effectively minimized with the aid of some simple but strategic tools, such as actions to increase awareness about its use. This study provides information on the dynamics of clam harvesting and the influence of time of day, tide, vacation–nonvacation period, stock (number and size), and mass-mortality events on the number of harvesters. The dynamics and intensity of clamming proved to vary over time (between the two biennia). In addition to information about the socioeconomic profile of the clammers, participatory planning strategies can be designed to allow communication between users, managers, and scientists to discuss best management practices for sustaining the *T. mactroides* fishery in Caraguatatuba Bay. Knowledge of the temporal dynamics of the activity may also inform proposals for education and communication strategies to reach most of the users.

For example, the mass-mortality events may have been caused by unsuitable sanitation or pollution conditions. On the other hand, if these mortality events occur naturally, due to a density-dependent phenomenon (e.g., Turra et al. 2014), people should be advised to exploit the clams as much as they want to, otherwise the resource will be lost. The clammers could also be informed about food safety if the quality of the clams is monitored. This study highlights the need for long-term monitoring of clam harvesting as an important part of managing this traditional and informal activity, to assess the possible risks of overexploitation, and to assure the safety of clam consumers and also provides important information to guide the adaptive management of this resource and this socioeconomic activity.

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REFERENCES

Abrahão, J. R., R. S. Cardoso, L. Q. Yokoyama, and A. C. Z. Amaral. 2010. Population biology and secondary production of the stout razor clam *Tagelus plebeius* (Bivalvia, Solecurtidae) on a sandflat in southeastern Brazil. Zoologia (Curitiba) 27:54–64.

Aburto, J., and W. Stotz. 2013. Learning about TURFs and natural variability: failure of surf clam management in Chile. Ocean and Coastal Management 71:88–98.

Araújo, C. M. Y. 2001. Biologia reprodutiva do berbigão *Anomalocardia brasiliana* (Mollusca, Bivalvia, Veneridae) na reserva extrativista marinha do pirajubaé. [Reproductive biology of the clam *Anomalocardia brasiliana* (Mollusca, Bivalvia, Veneridae) in the Marine Extractive Reserve of Pirajubaé.] Doctoral dissertation. University of São Paulo, São Paulo, Brazil.

Caddy, J. F. 1989. Marine invertebrate fisheries: their assessment and management. Wiley, New York.

Castilla, J. C., and O. Defeo. 2001. Latin American benthic shellfisheries: emphasis on co-management and experimental practices. Reviews in Fish Biology and Fisheries 11:1–30.

CETESB (Companhia Ambiental do Estado de São Paulo). 2013. Relatório de qualidade das praias litorâneas no estado de São Paulo [Report of quality of coastal beaches of the state of São Paulo.] CETESB, São Paulo, Brazil.

Chadsey, M., V. L. Trainer, and T. M. Leschine. 2012. Cooperation of science and management for harmful algal blooms: domoic acid and the Washington coast razor clam fishery. Coastal Management 40:33–54.

Chen, S. H. 1997. An investigation on the effect of arsenic poisoning on humans, agriculture, and fisheries. Journal of the Chinese Chemical Society 44:115–121.

Dadon, J. R. 2005. Changes in the intertidal community structure after mortality event in sandy beaches of Argentina. Contributions to Zoology 74:27–39.

Defeo, O., and A. MacLachlan. 2005. Coupling between macrofauna community structure and beach type: a deconstructive meta-analysis. Marine Ecology Progress Series 433:29–41.

Denadai, M. R., A. C. Z. Amaral, and A. Turra. 2005. Along-and across-shore components of the spatial distribution of the clam *Tivela mactroides* (Born 1778) (Bivalvia, Veneridae). Journal of Natural History 39:3275–3295.

Dunham, J. S., B. Koke, G. E. Gillespieand, and G. Meyer. 2007. An exploratory survey for littleneck clams (*Protothaca staminea*) in the Broughton Archipelago, British Columbia—2006. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2787.

Dyson, K., and D. D. Huppert. 2010. Regional economic impacts of razor clam beach closures due to harmful algal blooms (HABs) on the Pacific coast of Washington. Harmful Algae 9:264–271.

Griffiths, J., M. N. Dethier, A. Newsom, J. E. Byers, J. J. Meyer, F. Oyarzun, and H. Lenihan. 2006. Invertebrate community responses to recreational clam digging. Marine Biology 149:1489–1497.

Hartill, B. W., M. Cryer, and M. A. Morrison. 2005. Estimates of biomass, sustainable yield and harvest: neither necessary nor sufficient for the management of non-commercial urban intertidal shellfish fisheries. Fisheries Research 71:209–222.

Herrmann, M., D. Carstensen, S. Fisher, J. Laudien, P. E. Penchaszadeh, and W. E. Arntz. 2009. Population structure, growth, and production of the wedge clam *Donax hanleyanus* (Bivalvia: Donacidae) from northern Argentinean beaches. Journal of Shellfish Research 28:511–526.

Jorge, R. A. D. L. V. C. 2003. Avaliação de impacto ambiental sobre o ecossistema marinho utilizando larvas de mexilhões (*Perna perna*) (Linnaeus, 1758) (Mollusca:Bivalvia) como bioindicadores, através de técnicas ecotoxicológicas. [Assessment of the environmental impact on the marine ecosystem using mussels larvae (*Perna perna*) (Linnaeus, 1758) (Mollusca: Bivalvia) as bioindicators, through ecotoxicological techniques.] Doctoral dissertation. University of São Paulo, São Paulo, Brazil.

Laudien, J., T. Brey, and W. E. Arntz. 2003. Population structure, growth and production of the surf clam *Donax serra* (Bivalvia, Donacidae) on Namibian two sandy beaches. Estuarine, Coastal and Shelf Science 58(Supplement):105–115.

Lima, M., A. Brazeiro, and O. Defeo. 2000. Population dynamics of the yellow clam (*Mesodesma mactroides*): recruitment variability, density-dependence and stochastic processes. Marine Ecology Progress Series 207:97–108.

McLachlan, A., J. E. Dugan, O. Defeo, A. D. Ansell, D. M. Hubbard, E. Jaramillo, and P. Penchaszadeh. 1996. Beach clam fisheries. Oceanography and Marine Biology: an Annual Review 34:163–232.

Murray-Jones, S., and S. Steffe. 2000. A comparison between the commercial and recreational fisheries of the surf clam, *Donax deltoids*. Fisheries Research 44:219–233.

Narchi, W. 1976. Ciclo anual da gametogenese de *Anomalocardia brasiliana* (Gmelin, 1791) (Mollusca Bivalvia). [Annual cycle of the gametogenesis of *Anomalocardia brasiliana* (Gmelin, 1791) (Mollusca Bivalvia).] Boletim de Zoologia da Universidade de São Paulo 1:331–350.

Ortega, L., J. C. Castilla, M. Espino, C. Yamashiro, and O. Defeo. 2012. Effects of fishing market price, and climate on two South American clam species. Marine Ecology Progress Series 469:71–85.

Paes, E. T. 1989. Biologia e ecologia de *Donax gemmula* (Bivalvia, Donacidae) na zona de arrebentação da Praia do Cassino, Rio Grande, RS; e observações sobre a fauna acompanhante. [Biology and ecology of *Donax gemmula* (Bivalvia, Donacidae) in the surf zone of Cassino Beach, Rio Grande, RS; with comments on the accompanying fauna.] Master's thesis. Fundação Universidade do Rio Grande, Rio Grande, Brazil.

Prieto, A. S. 1983. Ecologia de *Tivela mactroides* (Born, 1778) (Mollusca, Bivalvia) en Playa Güiria (Sucre, Venezuela). [Ecology of *Tivela mactroides* (Born, 1778) (Mollusca, Bivalvia) at Güiria Beach (Sucre, Venezuela).] Boletín del Instituto Oceanográfico, Universidad de Oriente 22:7–19.

Schaeffer-Novelli, Y. 1980. Análise populacional de *Anomalocardia brasiliana* (Gmelin, 1791), na Praia do Saco da Ribeira, Ubatuba, Estado de São Paulo. [Population analysis of *Anomalocardia brasiliana* (Gmelin, 1791) at Saco da Ribeira Beach, Ubatuba, State of Sao Paulo.] Boletim do Instituto Oceanográfico 29:351–355.

Sims-Castley, R., and S. G. Hosking. 2003. A social cost-benefit analysis of a small-scale clam fishery in the Eastern Cape, South Africa. African Journal of Marine Science 25:159–168.

Turra, A., M. Petracco, A. C. Z. Amaral, and M. R. Denadai. 2014. Temporal variation in life-history traits of the clam *Tivela mactroides* (Bivalvia:Veranidae): density-dependent process in sandy beaches. Estuarine, Coastal and Shelf Science 150(Part A):157–164.

Viegas, O. 1981. Dinâmica populacional e produção de *Tagelus plebeius* (Solcurtidae: Bivalvia) no Canal do Calunga-Macéio-Alagoas. [Population dynamics and production *Tagelus plebeius* (Solcurtidae: Bivalvia) in the Channel Calunga-Maceió-Alagoas.] Doctoral dissertation. University of Brasília, Federal District, Brazil.

Wiber, M. G., M. A. Rudd, E. Pinkerton, A. T. Charles, and A. Bull. 2010. Coastal management challenges from a community perspective: the problem of "stealth privatization" in a Canadian fishery. Marine Policy 34:598–605.