

The relationship between human exploitation pressure and condition of mussel populations along the south coast of South Africa

Marc Rius*, Sven Kaehler* and Christopher D. McQuaid*[†]

Human exploitation of intertidal organisms in South Africa is an ancient activity based principally on mussels. We studied mussel populations and patterns of exploitation along a 160-km stretch of the south coast. Photographs (100 per site) were taken of the intertidal rocks at each of 14 sites, covering a range of exploitation intensities. Percentage cover was negatively correlated with number of mussel patches and positively correlated with mean shell width. PCA analysis identified groups of sites: a) accessible and unprotected sites: low cover, small mussels, patchy distribution; b) inaccessible sites and sites next to, or within, nature reserves: high percentage cover, large animals, less patchy distributions. Affluent coastal settlements also seem to confer protection against harvesting. Harvester distribution was examined by aerial surveys and combined with information on distance to the nearest beach access point and number of households within 7 km for each site. Sites within reserves and inaccessible sites had low densities of collectors, whereas sites near urban areas and in the Ciskei had the highest densities. All correlations between indicators of human exploitation and condition of mussel populations were non-significant. However, number of collectors showed positive trends with number of patches and negative trends for the two other variables. The results indicate much lower levels of exploitation than in the neighbouring Transkei region, and suggest a high degree of background variability in mussel population structure.

Introduction

Human exploitation of intertidal organisms on rocky shores is an important cause of disturbance to intertidal communities.¹⁻⁴ Excessive collection may lead to major changes in population structure and functioning⁵⁻⁸ and can seriously deplete stocks of intertidal organisms.^{9,10} The consequences of harvesting can be severe and can have direct effects on the community,¹¹⁻¹⁴ as most of the target species are occupiers of primary space, and some, such as mussels, may provide a substratum for other organisms, resulting in indirect effects on other species.¹⁵⁻¹⁸ In South Africa, 35 species of intertidal organisms are exploited,¹⁹ though the principal target species are mussels.²⁰⁻²²

Exploitation of intertidal organisms has existed in some indigenous cultures since prehistoric times²³⁻²⁵ and some of the earliest evidence of exploitation of marine molluscs comes from southern Africa, indicating that it has been practised since the Middle Palaeolithic Era (100 000 years ago).^{22,26-29} Over the last 10 000 years, significant changes have occurred in the way intertidal organisms have been exploited in southern Africa,^{19,30} with exploitation pressure increasing dramatically in recent times.^{14,31,32} Modern exploitation of marine resources comprises three types

of activity: recreational, commercial and subsistence.^{19,33} The type practised depends on many factors, including human demography, tradition, economy and so on. For example, exploitation of many marine organisms on rocky shores in Chile and South Africa is mainly for subsistence purposes,¹⁹ while in Australia and Portugal this activity tends to be recreational.^{25,34-36}

Intertidal exploitation activities along the South African coast differ markedly regarding types of harvesting methods. On the west coast, upwelling promotes primary production, which greatly enhances the availability of resources. Along this coast most intertidal exploitation is recreational.³⁷ On the south and east coasts, biological productivity is lower and fewer resources are available, but human population densities are much higher and subsistence harvesting (generally practised by poor people) is intense, especially on the southeast and east coasts.^{31,38} The south coast is a popular tourist destination, and recreational collection by holidaymakers can be heavy during the peak holiday seasons.³⁹

Despite the abundance of mussels along both the west and southwest coasts of South Africa, their exploitation is minimal in these regions.³⁹ In contrast, along the southeast and east coasts the situation is very different. The politically motivated establishment of 'homelands' during the apartheid era resulted in the black African population becoming concentrated, the main coastal concentrations being in the former Ciskei, Transkei and Zululand (now KwaZulu-Natal) regions. Coastal inhabitants of these regions have long supplemented their traditional maize-based diet with marine invertebrates. In recent years, there has been an increase in intensity of subsistence exploitation due to population growth and poverty,^{19,40} with marked effects on intertidal communities.⁴¹⁻⁴³

Subsistence exploitation in South Africa shows a particular pattern of shoreline utilization as it is normally restricted to periods of spring tides and takes place during all seasons.⁴⁴ This activity tends to be selective, both in terms of the species and size of the individual removed. In most cases the largest individuals of a target species are removed, and these are also the main contributors to population spawning events.^{7,34,35} In the case of molluscs, exploitation is highly selective, affecting the largest and most fecund individuals.^{1,46} Exploitation of mussels is especially destructive as selection often occurs after the removal of large clumps of animals.^{36,47} The effect of this is increased because mussels are gregarious⁷ and because recruitment preferentially occurs around the periphery of existing clumps of adults.⁴⁸⁻⁵⁰

Most studies of marine intertidal resource exploitation compare non-affected sites (normally coastal zones that are protected by law) and affected sites.^{3-5, 50} South Africa currently has 57 marine protected areas (MPAs) that receive some form of protection.³² Various studies have examined the effects that these MPAs have on mussel populations in South Africa^{7,30,44,47,52} and marked differences have been found between size-frequency

*Coastal Research Group, Department of Zoology and Entomology, Rhodes University, P.O. Box 94, Grahamstown 6140, South Africa.

[†]Author for correspondence. E-mail: c.mcquaid@ru.ac.za

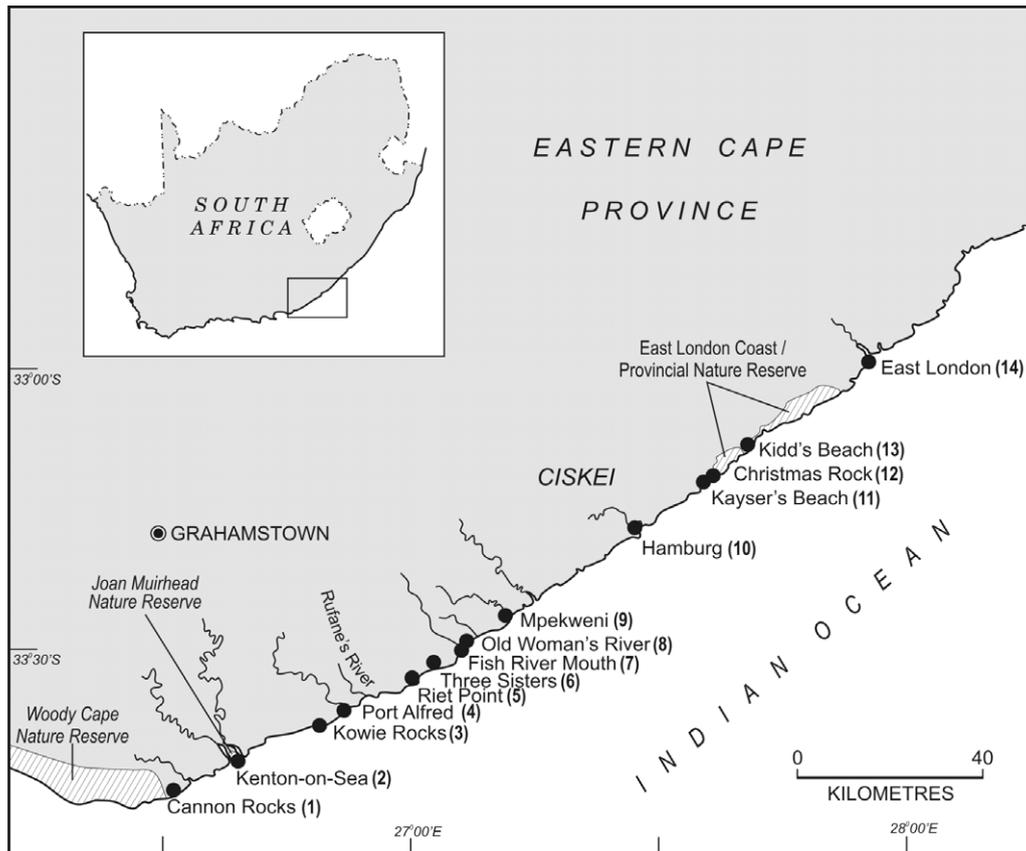


Fig. 1. Map of the study coastline. The study sites (1 to 14), additional sites, regions, and rivers are represented. Nature reserves are indicated by hatching.

distributions and biomass of exploited stocks relative to their counterparts in protected areas. However, studies of patterns of shoreline utilization along the coast of South Africa are scarce and generally performed at a small scale, e.g. ref. 38. Aerial surveys have been conducted only along the Cape Peninsula^{37,53} and along the Transkei coast.²⁰ The aims of this paper are to report mussel populations and patterns of human exploitation along an extensive stretch of the south coast, and to examine correlations between exploitation pressure and the condition of these mussel populations.

Materials and methods

Study location

The study region extended between Cannon Rocks (33°45'S, 26°33'E) and East London (32°97'S, 27°87'E) on the south coast of South Africa (Fig. 1). This covers approximately 160 km of coast of which 47 km (30%) is rocky shore, consisting primarily of a series of quartzitic sandstone or dune rock (aeolianite) platforms and headlands separated by sandy beaches.²²

From a preliminary survey in this region, 14 study sites were selected to cover a range of levels of exploitation and their mussel populations were surveyed (Fig. 1). All sites are exposed to the prevailing westerly swell.

Four study sites (Cannon Rocks, Kenton-on-Sea, Christmas Rock and Kidd's Beach) were located in or next to three coastal nature reserves (see Fig. 1) that supposedly confer protection on intertidal animals.²² Of the remaining nine sites, three were easily accessible to people and situated next to urban areas (East London, Port Alfred, Kayser's Beach); one was accessible and in the former Ciskei homeland (Hamburg); and the rest (Kowie Rocks, Riet Point, Three Sisters, Fish River Mouth, Old Woman's River, Mpekweni) were sites which are difficult to reach, either

because access is restricted (e.g. by landowners) or because they can be reached only by walking long distances.

Mussel surveys

Two exploited mussel species were studied: the invasive Mediterranean mussel *Mytilus galloprovincialis* (Lamarck) and the indigenous brown mussel *Perna perna* (Linnaeus). Earlier observations indicated that harvesters do not choose between species when collecting mussels.

A single mussel survey was conducted at each site between June 2003 and April 2004. One hundred digital photographs of the intertidal rock surface were taken at each site using randomly placed 0.5 × 0.5 m quadrats. The areas sampled were within the limits of mussel bed distribution, in the mid or low mussel zones (where exploitation pressure is greatest, pers. obs.). The photographs were analysed using the computer program SigmaScan Pro 5 (SPSS Inc.) to estimate percentage mussel cover, mussel shell width and the number of mussel patches in each photograph.

The number of photographs required to analyse each site was determined in a preliminary study, using the method for the determination of sample size described in Zar.⁵⁴ We used a 0.05 level of significance with a 90% chance of detecting a mean significantly different from $\mu_0 = 0$ by as little as 7.5% cover. One hundred photographs were taken in an accessible and thus supposedly exploited site (Hamburg) and a non-accessible and thus non-exploited site (Riet Point) (Fig. 1). For the first site the required sample size was $n = 50.3$ and for the second $n = 35.4$. Examination of two more sites, one away from any population centre (Old Woman's River), and the other site close to Port Alfred (Rufane's River) (Fig. 1), showed a required sample of 18.1 and 88.0, respectively.

Because of the upright orientation of mussels on the shore,

shell width is the most reliable measure of size when analysing photographs. However, an estimate of maximum length was measured from one of the present study sites. A sample ($n = 100$) of *P. perna* was collected and measurements of the shell (width and length) were taken. As a result, a linear regression between width (y) and maximum length (x) for *P. perna* ($y = 0.45x + 4.13$; $n = 100$, $r^2 = 0.58$, $P = 0.0003$) was obtained. From the photographs of the mussel beds, shell width was measured to the nearest millimetre for the five largest individuals in each photograph (i.e. 500 mussels per site). The biggest mussels were considered to be the first animals that the harvesters would collect.^{1,46,55}

Indicators of exploitation pressure

To determine where the harvesters were distributed along this coast, three indicators of exploitation pressure were used: aerial surveys counting the number of collectors, the number of households in the vicinity of the study sites, and the distance from these sites to the nearest beach access point.

Eight aerial surveys of the study area were conducted during spring low tides (14 and 28 February 2002, 10 December 2003, 21 February, 22 April, 6 May, and 1 September of 2004 and 10 February 2005) from a high-winged aeroplane. The time taken to fly the 160 km was approximately one hour. The survey was conducted twice each day during the outbound (starting one hour before low tide time) and inbound legs of the flight. During each survey, the numbers of collectors on the shore were counted for 1-km stretches. Collectors were distinguished from other people on the shore (that is, those taking recreation and anglers) because they were observed to be harvesting or searching on rocky platforms, frequently also carrying bags for storing collected animals. It was assumed that any collector within a 1.5 km radius of a study site could potentially affect that site.

Spatially referenced data provided by the Chief Directorate of Surveys and Mapping of the Department of Land Affairs and the computer program ArcView GIS 3.2 (Environmental Systems Research Institute, Inc.) were used to determine the distance from each study site to the nearest access point (that is, the closest beach entrance that accesses the study site) and to count the number of households within a 7 km radius of each site. This distance was chosen based on previous interviews indicating that subsistence collectors were found to travel up to 7 km to sites in order to collect intertidal organisms (S. Kaehler, unpubl. data).

Data analysis

The data obtained from the mussel surveys failed to meet the assumptions of parametric ANOVA, even after transformation, and were tested using the non-parametric Kruskal-Wallis tests. Significant results were explored using Multiple Comparisons Kruskal-Wallis tests. Because the data were balanced and samples were relatively large, the results of Kruskal-Wallis tests were also examined using ANOVA.⁵⁶ This produced the same results as Kruskal-Wallis ANOVA and only the latter are reported here. Principal components analysis (PCA) was used to examine the relationships among the biological variables, and between these variables and indicators of human pressure.

All tests were analysed using the STATISTICA computer program (version 6.1) and a critical probability of 5%.

Results

Mussel surveys

Data on percentage mussel cover, maximum shell width and number of mussel patches are summarized in Fig. 2. At sites

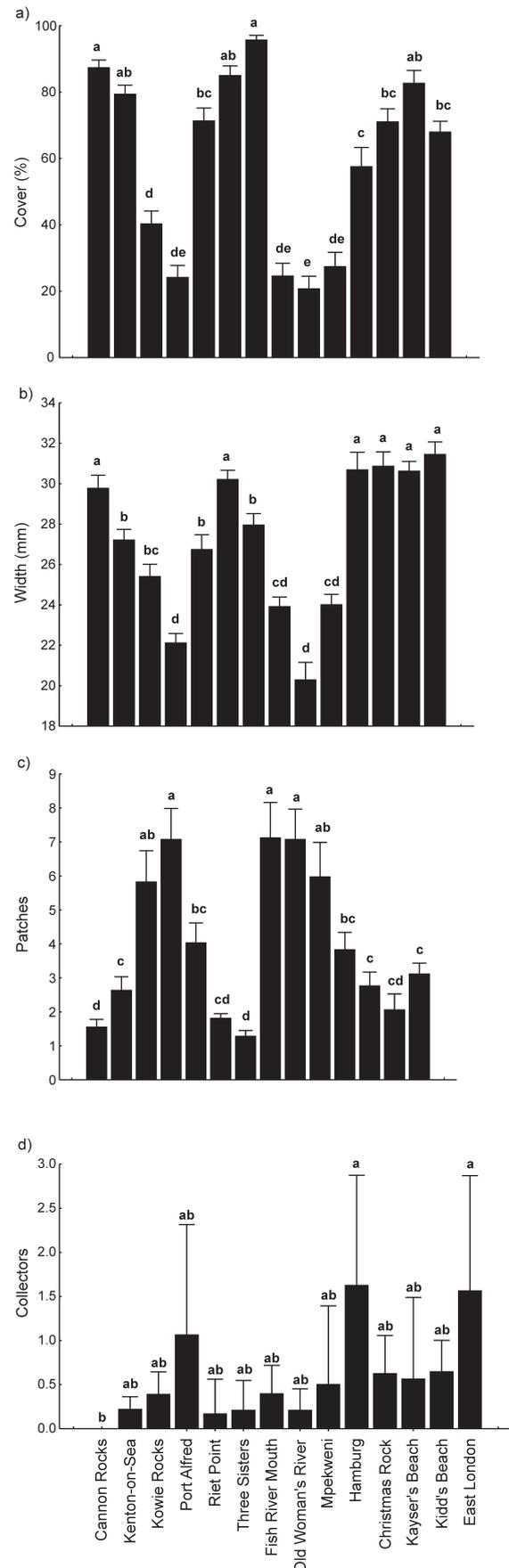


Fig. 2. (a) Mean percentage mussel cover, (b) mean shell width (mm), (c) mean number of patches and (d) mean number of collectors within a 1.5-km radius from each site. Data pooled from all surveys. Vertical bars denote 95% confidence intervals. Letters indicate homogeneous groups as determined by Multiple Comparisons Kruskal-Wallis tests.

where mussel cover was low, shell width was small and the mussel community patchier, whereas at sites where percentage mussel cover was higher, the largest mussels were bigger and their distribution less patchy.

These three variables were scanned for possible correlations. Percentage cover was significantly negatively correlated with number of patches and positively correlated with shell width (Pearson correlation, $r = -0.65$ and 0.60 , respectively, $P < 0.001$ in both cases).

Kruskal-Willis ANOVA revealed strong site effects for all three variables ($H(13, N = 1400) = 915.9, 782.4, 538.6$, respectively; $P < 0.0001$ in all cases). The results from the Multiple Comparisons Kruskal-Wallis test (Fig. 2) identified different groups of sites that can be summarized in two main groups when the three variables are compared together. The first group was formed by the sites with low cover, small mussels and patchier distribution: Port Alfred, Old Woman's River, Mpekweni and Hamburg. The second group included the remaining sites, firmly represented by sites like Cannon Rocks, Three Sisters or Kidd's Beach, with high percentage cover, large animals and less patchy distribution. Kowie Rocks was intermediate; included in the first group in terms of percentage cover and number of patches and in the second for mussel size.

The first factor in the PCA analysis defined $>90\%$ of variability between sites and was directly proportional to shell width and percentage cover of mussels and inversely proportional to number of patches (Fig. 3a). These results were in accordance with the Pearson correlations reported above. The distribution of the sites in the PCA graph conformed to the groupings found in the multiple comparison analysis (Fig. 3b).

Indicators of exploitation pressure

Nature reserves and protected sites showed low densities of collectors, while sites next to urban areas and in the Ciskei showed the highest densities (Fig. 2d). The data were not normally distributed ($P < 0.001$), and the Kruskal-Willis ANOVA test showed significant differences among sites ($H(13, N = 112) = 38.02, P < 0.001$). Multiple comparisons tests showed that Cannon Rocks had significantly ($P < 0.05$) fewer collectors than Hamburg and East London, with the remaining sites forming a continuum between these two sites (Fig. 2d).

In order to find correlations between the indicators of exploitation and the biological data, each indicator was correlated with the three variables from the mussel surveys. All analyses showed weak relationships between exploitation and the condition of mussel populations (Pearson correlation test, $P > 0.05$ in all cases). The strongest correlations were between numbers of collectors and the biological data. In these analyses, an outlier (East London) was detected (Cook's distance was $0.562, 1.006, 0.491$ for percentage cover, width and patches, respectively, i.e. $<$ critical value in all cases) and removed. The best-fitting regressions were logarithmic. Although all correlations were non-significant ($P > 0.05$), the trends were positive among number of collectors and number of patches and negative among number of collectors and the other two variables (Fig. 4).

Discussion

This work is the first approach to the study of human exploitation on mussel populations along an extensive stretch of the south coast of South Africa. The study found that protected and inaccessible sites exhibited healthier mussel populations, while at accessible and unprotected sites, reduced cover and abundance of large mussels were encountered. This suggests that in the area studied only readily accessible mussel populations are adversely

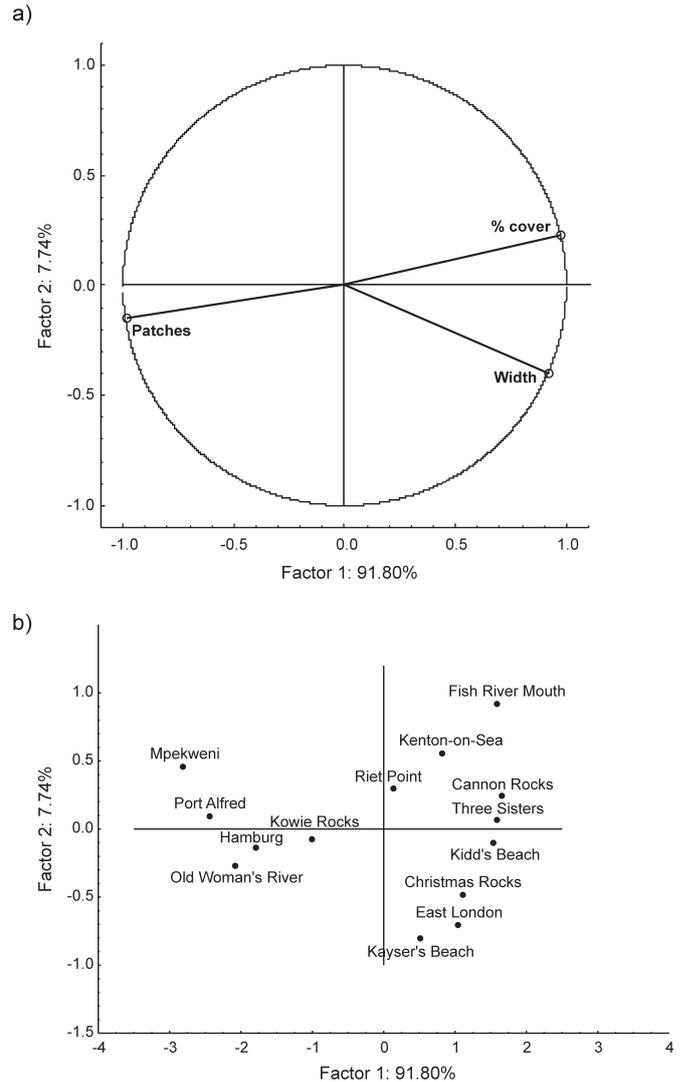


Fig. 3. PCA graphs representing (a) the three biological variables and (b) the study sites.

effected by human collectors. Nonetheless, owing to high background variability, no statistically significant correlations were found between indicators of exploitation pressure and the status of mussel populations.

One indicator of stock depletion of mussel populations is to compare size of mussels at sexual maturity and the preferred collection size for shellfish gatherers. If the size at sexual maturity is less than the collected size, the exploited animals normally include reproducing individuals. If, however, the size at maturity is greater than the collected size, there is a serious risk that removal of large numbers of reproductively active individuals will drastically reduce the reproductive output of the population.⁷ In the current study, measurements of maximum shell width reflected a reduced mean size of the largest mussels in unprotected sites compared to inaccessible sites. The size of *P. perna* at sexual maturity is 25–30 mm total length,⁷ which is equivalent to a shell width of 15.4–17.6 mm (see Materials and methods). The smallest mean maximum shell width was 20.2 mm (found at Mpekweni), which corresponds to a length of 35.9 mm. Thus, the biggest mussels at all study sites were larger than the size at sexual maturity, suggesting that harvesting pressure is not severe enough to cause reproductive failure.

Mussel cover was positively related to mussel size and negatively related to number of mussel patches. This indicates that at

sites where mussel distribution was patchier, mussel cover was also lower and mussels smaller, presumably due to the effects of human exploitation. All three variables showed significant differences among the various sites, which could be separated into two groups (Fig. 3b). The PC1 axis accounted for >90% of variability among sites and, along this axis, nine sites showed positive values, i.e. they displayed the least signs of exploitation, having high mussel cover, low patchiness and large mussels (see Fig. 2).

Non-exploited sections of the coast may act as important 'buffer zones' or 'source areas' from which species can recolonize providing recruitment to adjacent shorelines where collection takes place.¹⁹ However, in Algoa Bay, on the study coast, McQuaid and Phillips⁵⁷ concluded that the great majority of successful recruits appeared within 5 km of the source population, and, in KwaZulu-Natal, an absence of adults and recruits has been registered despite an existing source of larvae next to exploited sites.⁴² Along the studied coastline, extensive sections of shore are inaccessible to man or are proclaimed nature reserves and, as a result, they support very low human population densities. Such macro-spatial refuges may be critical in promoting long-term recovery of exploited populations, in preventing species extinctions and long-term or irreversible disequilibria.⁸ The sites from the first group (positive values of the principal component 1 at the PCA analysis) had a mean mussel cover >50%, and mean shell width larger than 26 mm (i.e. mean maximum length of 48.6 mm): four were within or immediately next to a nature reserve, three more (Riet Point, Three Sisters, Fish River Mouth) were sites with difficult access, and another two (Kayser's Beach and East London) were situated next to urban centres. These last two sites were accessible and non-protected areas, but they were close to affluent settlements, which seemingly confer protection against illegal harvesting of intertidal animals. Interviews with local residents revealed that they do not allow any subsistence collectors to undertake any illegal activity on the shore near their houses.

Worldwide, wherever poor communities are situated next to protected areas, tensions exist between the demands for access and use of resources versus the needs for conservation and management. In South Africa, some MPAs are under threat, especially in the Transkei region. Political transformation in the country has led to expectations that land previously set aside for conservation may be re-allocated, and several legal land-claims have been made in order to achieve this.³² Our findings suggest that, along the stretch of coast studied, the existing nature reserves effectively protect mussel populations, including sites on the boundaries of reserves.

In contrast to these protected sites, the PCA showed five sites that were located in the negative value region of factor 1 (Fig. 3b). These were sites where mean shell width and percentage mussel cover were the lowest and mean number of patches the highest. Hamburg is an accessible site in the Ciskei region (one of the former homelands), where, as on the Transkei coast, subsistence exploitation affects mussel stocks enormously.^{30,44} Port Alfred is an urban centre and an important tourist destination, which suggests that seasonal recreational exploitation may affect mussel populations, while throughout the year subsistence collectors coming from the areas where the African population and poverty are concentrated, harvest in the same area. Kowie Rocks is a site with difficult access but it is close to Port Alfred (c. 5 km away). Within this group of exploited sites, Kowie Rocks showed the least signs of degradation in mussels populations (Fig. 2). Old Woman's River and Mpekwani are far from urban areas, but at both sites a hotel is adjacent to the sampling site.

Access is normally restricted to guests and staff of the hotel, and recreational exploitation by these people could therefore be responsible for the low abundance and size of the mussels found there. However, an alternative and more likely explanation is that this result reflects the high degree of background variability that exists among these populations, regardless of exploitation.⁴⁹

The aerial surveys showed that this coastline is not as highly exploited as the nearby Transkei coast. During these surveys, a total of 0.61 collectors per km per survey was recorded, while in comparison, on the Transkei coast Hockey *et al.*²⁰ counted 2.35 collectors per km per survey. Popular sites where people could always be found harvesting were easily identified, but never at the same densities as in the Transkei, where Mills⁵⁵ found that the densities of collectors in one location had increased from 5 to 20 collectors per km in the last 30 years. Mills⁵⁸ also recorded that during one day in the middle of a drought 316 women were observed collecting intertidal organisms at a single site.

In our aerial surveys, sex, age and race of the collectors could not be determined, although most of them appeared to be African men followed by white males. In the Transkei, Hockey *et al.*²⁰ recorded that 91% of the collectors were Africans and the remainder were whites, whereas 81% of all collectors were women.

No statistically significant correlations were found between the indicators of exploitation pressure and the variables found from the mussel surveys. However, the number of collectors was negatively related to maximum shell width and percentage mussel cover, and positively to number of patches (Fig. 4). A possible reason for the lack of significant correlations is that people observed from the plane may have been collectors of other organisms (for example, abalone or alikreukel) and not of mussels, or that they were not collectors but recreational people observing the rocky shores (particularly at East London). Another explanation could be that the instantaneous average number of collectors does not provide sufficient information about harvesting effort to provide good correlations with remaining stocks. The aerial surveys recorded instantaneous estimates of harvester densities and give an indication of average numbers. Sporadic periods of intense exploitation, as reported by Mills,⁵⁸ could result in devastating effects on mussel populations but would be missed by this approach.

For the other two indicators of exploitation (that is, number of households and access points), weak patterns were found. At sites where the distances to access points were low and density of households was high, low mussel abundance was encountered. Similarly, Addressi¹³ showed that there are gradients of human disturbance, depending on the distance from the access point, and Rius and Cabral³⁶ found a negative correlation between accessibility to sites and abundances of mussels. On the Transkei coast, collectors walk an average of 1.5 km between home and the intertidal zone to gather mussels and other organisms during low spring tides. Other collectors living as far as 10 km inland, visit the shore on foot, but these people restrict their visits to the coast to one or at most two days per month, when low spring tides coincide with favourable weather.^{20,58} As a result, subsistence collectors are not expected to travel from farther than 10 km, which means that collectors from one of our study sites would most likely not travel to another of the study sites to collect mussels.

The existing data provide an initial database for further monitoring studies, from which a management plan for this specific area can be proposed. Factors such as background spatial and temporal variability, as well as the presence of affluent settlements, must be taken into consideration, but it

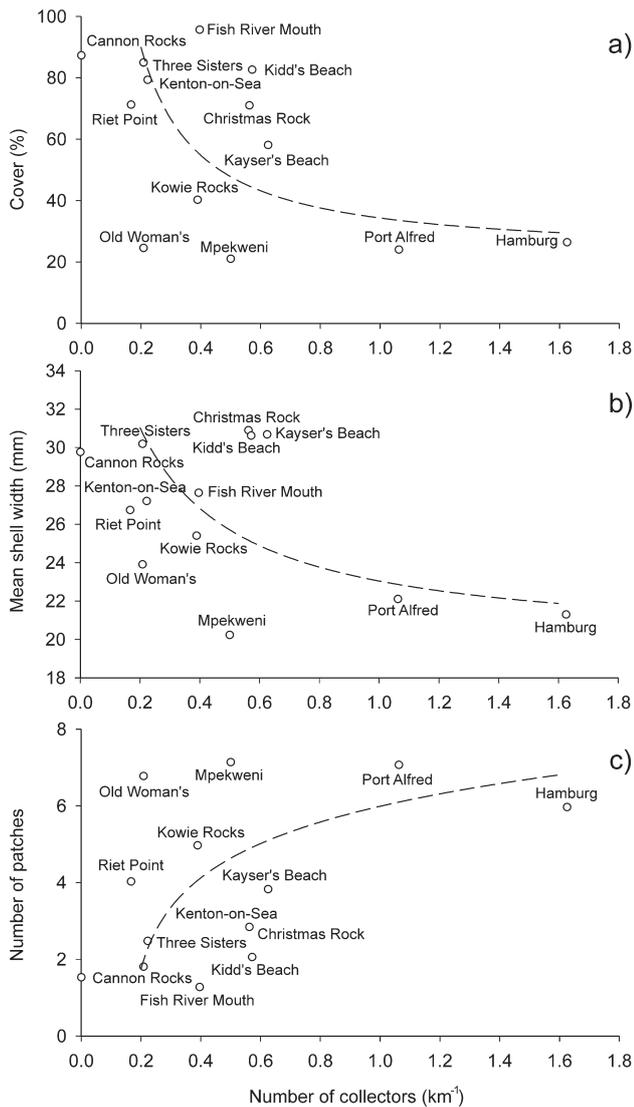


Fig. 4. Mean number of collectors plotted against the biological variables: (a) mean percentage mussel cover; (b) mean shell width; (c) mean number of patches. A logarithmic fit is represented. East London was an outlier and was excluded from the analysis.

appears that exploitation of mussels along the coastline studied is less intense than in the Transkei. However, long-term biological studies linked to socio-economic studies of the region are necessary to design a holistic approach to the management of intertidal resources along this coast.

This work was supported by a 'beca MAE-AECI' to M.R. from the Spanish Ministerio de Asuntos Exteriores and by funding from the National Ports Authority of South Africa, the NRF and Rhodes University. We would like to thank V. Gaudin, L. Proudfoot and D. Samuel for assistance in the fieldwork.

Received 7 June. Accepted 27 November 2005.

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