Presented at the 2nd National Conference on Coastal Areas Research. Maputo, 27-29 Spetember, 2000

A Preliminary Investigation of the Effects of Human Physical Disturbance on the Ecology of the Soldier Crab *Dotilla fenestrata* (Crustacea, Ocypodidae) at Praia da Costa do Sol, Maputo

Marcos A. M. Pereira[1] & Paulo Miguel B. Gonçalves[2]

[1] CDS das Zonas Costeiras (Xai-Xai) – MICOA. e-mail: coastal@tropical.co.mz
[2] e-mail: chifununo@yahoo.com

ABSTRACT
The effects of human trampling on the population parameters of the soldier crab *Dotilla fenestrata* at Praia da Costa do Sol, Maputo were studied in two areas subjected to two different levels of human disturbance: (1) a low disturbance area; and (2) a high disturbance area. Sampling was carried out 1 day before and 1 day after disturbance took place and crab abundance and biomass data were compared between the two periods at each area. No significant differences ($P > 0.05$) were found between abundance and biomass values before and after the disturbance. These results suggest that human trampling has an insignificant effect on *D. fenestrata* and that behavioral and habitat structure aspects might play more important roles on the population ecology of the soldier crab at Praia da Costa do Sol.

RESUMO
O efeito do tráfego pedestre sobre alguns parâmetros populacionais do caranguejo soldado *Dotilla fenestrata* na Praia da Costa do Sol, Maputo foram estudados em duas áreas com diferentes níveis de distúrbio humano: (1) uma área de baixo distúrbio; e (2) uma área de alto distúrbio. A amostragem foi efectuada 1 dia antes e 1 dia após o distúrbio e dados sobre a abundância e biomassa dos caranguejos foram comparados entre os dois períodos, para cada área. Não foram encontradas diferenças significativas ($P > 0.05$) entre os valores de abundância e biomassa antes e após o distúrbio. Estes resultados sugerem que o distúrbio provocado pelo tráfego pedestre possui um efeito insignificante sobre *D. fenestrata* e que aspectos comportamentais e relacionados com a estrutura do habitat possam ter um papel mais importante sobre a ecologia populacional do caranguejo soldado na Praia da Costa do Sol.

INTRODUCTION

Intertidal areas worldwide are subjected to considerable and increasing anthropogenic influences that range from direct physical disturbance (e.g. trampling, driving, commercial and recreational harvesting of plants and animals and coastal development) to indirect biological and chemical disturbance (eutrophication, urban runoff, chemical and thermal pollution, freshwater discharges, introduction of alien species). This has led to a loss of biodiversity, a decrease in the standing stocks of resources and the alteration of ecological processes (e.g. distribution, species interactions, abundance, population structure, reproductive success) (Brosnan & Crumrine, 1994; Raffaelli & Hawkins, 1996; Ruwa, 1996; Stark, 1998; Brown & Taylor, 1999; Lercaria & Defeo, 1999; Schiel & Taylor, 1999).

One type of human physical disturbance that has not received much attention is trampling (i.e., pedestrian traffic). Very few studies have investigated this disturbance factor and those conducted used mostly sessile organisms (e.g. macroalgae, bivalves, barnacles) from temperate rocky shores (e.g. Beauchamp & Gowing, 1982; Ghazanshahi *et al*., 1983; Povey & Keough, 1991; Brosnan & Crumrine, 1994; Keough & Quinn, 1998; Brown & Taylor, 1999; Schiel & Taylor, 1999) or subtropical regions (Bally & Griffiths, 1989). There is a clear lack of studies investigating human physical disturbances on tropical soft-bottom intertidal areas, which are often subjected to considerable physical disturbances. This is a characteristic situation in Maputo Bay, where exploitation of intertidal resources for subsistence is high (Gujral, 1995; Longamane, 1995; de Boer & Longamane, 1996; Pereira, 1998).

Maputo Bay has been exploited for its marine resources since early colonial times and tourism has become an important industry since the end of the 14 years civil war, in 1992.

The tourism activity is focussed mostly in three areas: Inhaca Island, the Macaneta Peninsula and Praia da Costa do Sol in Maputo City.

Praia da Costa do Sol, the most visited, disturbed and less studied of the three areas, is subjected to a variety of human disturbances including pollution from land-based sources (e.g. industrial, agro-chemical and sewage) (Fernandes *et al.*, 1993; Fernandes, 1996) and recreational use (especially during holidays and weekends – pers. obs.).

This study aimed to explore a different approach in the investigation of the impacts of human trampling on intertidal organisms, by studying a soft substratum and a non-sessile organism. The main objective of this investigation was to examine the effects of trampling by humans on the population structure, abundance and biomass of the soldier crab *Dotilla fenestrata* (Hilgendorf, 1869) along Praia da Costa do Sol.

D. fenestrata is very abundant in Maputo Bay and plays a major role in the ecology of sandy shores, occurring in local high density patches (Paula & Dray, 1995). These crabs are responsible for a rapid sediment turnover and contribute significantly to the consumption of the available organic matter in the superficial layer of the sediment (Fishelson, 1983; Paula & Dray, 1995). Additionally they constitute an important prey item for the local bird communities (de Boer & Longamane, 1996; J. Paula, pers. com.; and pers. obs.).

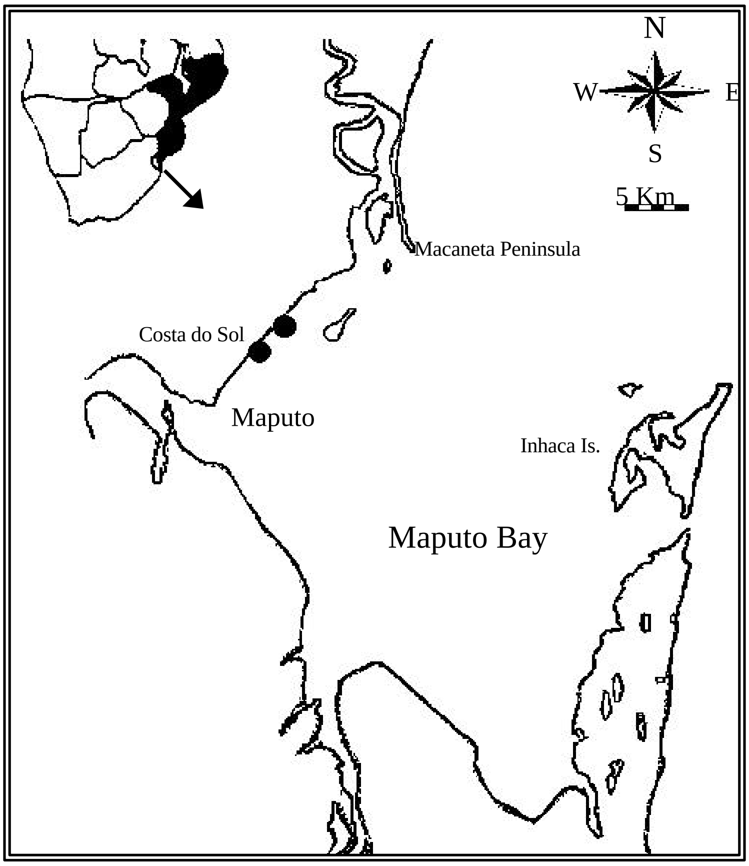

Figure 1. Map showing sampling locations (dark circles) and sites mentioned in the text.

MATERIALS AND METHODS

Study Area

Maputo Bay is located in the south of Mozambique (Figure 1), has an estimated area of 960 km^2 and is roughly horseshoe shaped, opening to the Indian Ocean to the north (Kalk, 1995). Five large rivers flow into the Bay on its western boundary and reach the Indian Ocean northwards. The Bay is shallow, only one fifth of its area is deeper than 10 m (at low tide) and the intertidal area of 234 km^2, almost equals a quarter of the total area (de Boer & Longamane, 1996). Tides are semi-diurnal, with a maximum spring tidal range of 3.9 m.

The study area lies within the region of transition from a warm temperate to a tropical climate with a pattern of hot (not very wet) summers and dry winters. The mean annual rainfall is 793 mm (1951-1997 data from Instituto Nacional de Meteorologia – INAM, Maputo) and the mean monthly temperature ranges from a maximum of 26.1° C in January, to a minimum of 19.3° C in July (1961-1990 INAM data).

Praia da Costa do Sol is situated approximately 6 km north of Maputo City (Figure 1). Large flat sand areas that become exposed at low tides characterise this side of the Bay. Small patches of seagrasses, dominated by the African eelgrass *Zostera capensis* and seaweed flora, mainly *Enteromorpha* spp. and *Ulva* spp. are common (Bandeira, 1995). The soldier crab *D. fenestrata* dominates the fauna of the sandbanks, being the main deposit feeder, with densities as high as 783 ind/m^2 (Afonso, 1996). Other brachyuran crabs occur in the area, the family Ocypodidae being most common. Also common are the anomuran hermit crabs *Diogenes* spp.

Two areas with distinct human disturbance levels were empirically chosen:

(i) *Low disturbance area*. Situated in front of Bairro da Costa do Sol, the sampled areas were sandbanks located at the low intertidal level. This area was considered as having low levels of trampling disturbance due to low number of visitors, mostly locals collecting intertidal mollusks.

(ii) *High disturbance area*. Extending from the Helena Park to the Costa do Sol restaurant, the sampled areas were sandbanks located at the high intertidal level. There are high levels of trampling disturbance in this area, mainly caused by people playing soccer.

Methods

Preliminary survey

Sampling size was determined using the performance curve method (Krebs, 1989). The cumulative mean number of crabs was plot against the number of samples collected (Figure 2). The curve started to stabilise at 5 samples. This was also, the number of samples collected by Afonso (1996) in the same study area. In the preliminary study, we also studied the relationship between crab individual weight (total crab fresh weight per total number of crabs at each replicate) and the number of juveniles using linear regression (Figure 3). A highly significant relationship was found (df = 26, $F_{(0.05),1,26}$ = 19.89, P < 0.001) as little crab weight less.

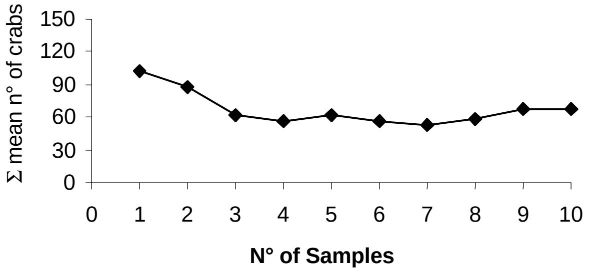

Figure 2. Performance curve for *D. fenestrata* at Costa do Sol.

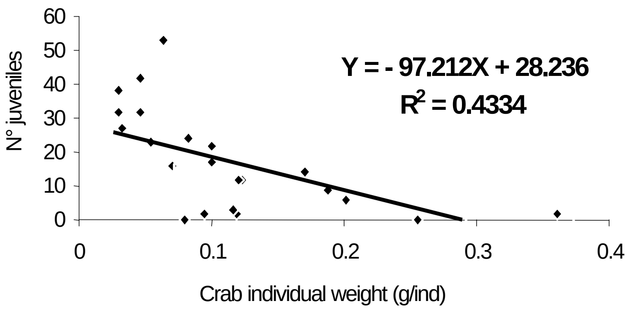

Figure 3. Relationship between crab individual weight and number of juvenile crabs at Costa do Sol.

Crab sampling

The crab sampling completed between July and August 2000. At each study area two sampling stations were established. Sampling took place 1 day before and 1 day after weekend days (Saturdays and Sundays), which are the days with the highest level of disturbance due to high number of people visiting the beach. During low spring tides, at each station, 5 randomly located replicates were taken. Crabs were collected using a 0.5 x 0.5-m metallic core, sieved through a 1.0 mm mesh sieve and taken to laboratory for analysis.

Laboratory and Statistical Analysis

Crabs were sorted and counted per replicate. Wet weight (WW) was measured and converted into ash free dry weight (AFDW) using a conversion constant of 0.022 obtained from biometric formulae (power functions) relating carapace width to WW and AFDW (de Boer & Longamane, 1996).

The Mann-Whitney *U*–test (Zar, 1999) was used to compare crab data before and after disturbance at each sampling station. Differences were considered significant at $P < 0.05$. Data analyses were done using the STATISTICA 4.5 (StatSoft Inc., 1997) software package.

RESULTS

Abundance

Crab mean abundance ranged from a minimum of 172 ind/m^2 at sampling station A in the low disturbance area to a maximum of 418 ind/m^2 at sampling station A in the high disturbance area (Figure 4). In general, the low disturbance area showed lower mean abundance values (204.4 ind/m^2) when compared to the high disturbance area (353.2 ind/m^2).

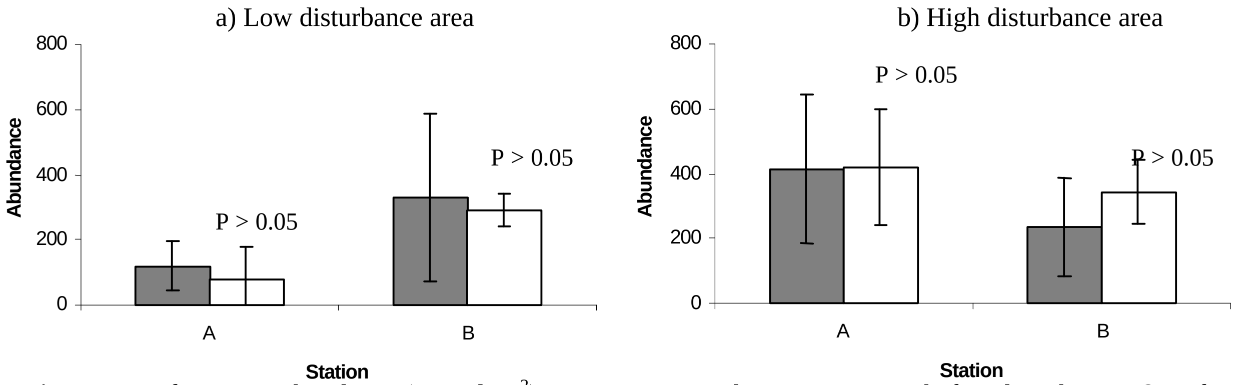

Figure 4. *D. fenestrata* abundance (N° ind/ m^2) variation in sampling stations. ■ – before disturbance; €– after disturbance. Bars are standard deviation.

In general, there were no significant differences between crab abundance before and after disturbance for both the high disturbed and low disturbed areas (Figure 4)

Biomass

Biomass values ranged from a minimum of 0.14 AFDW g/m^2 at sampling station A in the low disturbance area to 1.00 AFDW g/m^2 at sampling station B in the low disturbance area. Overall, mean biomass was 0.87 AFDW g/m^2 in the high disturbance area and 0.43 AFDW g/m^2 in the low disturbance area.

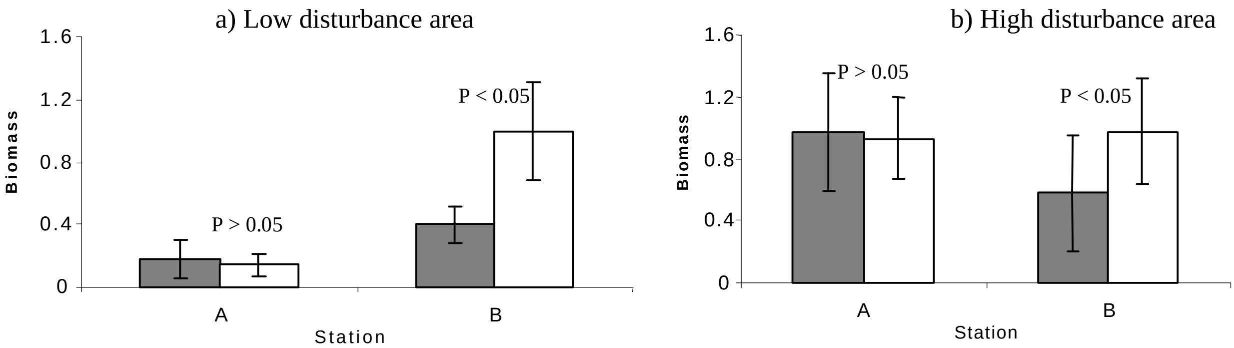

Figure 5. *D. fenestrata* biomass (AFDW g/m^2) variation in sampling stations. ■ – before disturbance; €– after disturbance. Bars are standard deviation.

Biomass values followed a similar pattern to the abundance values; with two exceptions: sampling station B in the low disturbance area and sampling station B in the high disturbance area showed significant higher values of biomass after the disturbance period ($P < 0.05$) (Figure 5).

Population Structure

In general, adults, both in high and low disturbance areas (Figure 6), dominated *D. fenestrata* populations with the exception of sampling station A in the low disturbance area.

Sampling station B, in the low disturbance area, showed a significant decrease in the abundance of juveniles between sampling events (Figure 6a). All other sampling stations showed no significant differences between the two periods (Figure 6a, b).

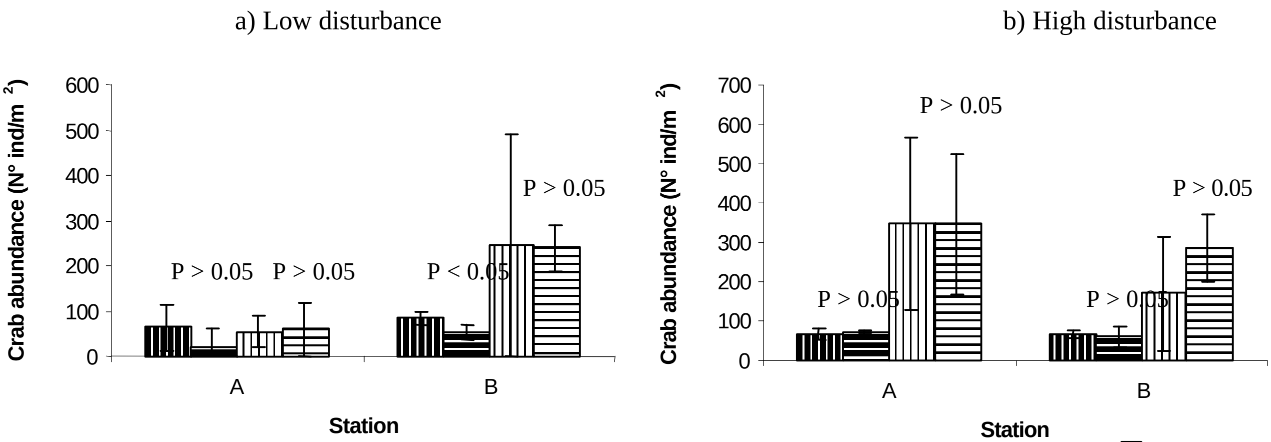

Figure 6. *D. fenestrata* population structure variation in sampling stations: ■ – juveniles; ⊜ – adults; ◫ – before disturbance; ⊟ – after disturbance. Bars are standard deviation.

DISCUSSION

Although a clear difference was observed in the field, a statistical comparison between the low and high disturbance areas' crab abundance was not detected due to the obvious habitat differences between them. Sediment characteristics (presence of broken shells, median grain size, water table depth, anoxic layer depth), tidal level and the presence of a small mangrove forest that could act as an input source of organic matter and other food materials (pers. obs.) could influence crab abundance (Hartnoll, 1973). This may bias the result of a strictly human physical impact-based comparison between the two areas. Predation by coastal birds might be another aspect that could contribute to this difference. At Costa do Sol (pers. obs.), as been reported elsewhere (Fishelson, 1983; de Boer & Longamane, 1996; J. Paula, pers. com.), *Dotilla* species are one of the most important intertidal food sources for coastal bird communities. As humans less often visit the low disturbance area there is a possibility that a greater predation pressure might be found in this area. At Inhaca Island, for example, de Boer & Longamane (1996) reported that foraging activities by coastal birds decreased when humans approached them.

Mean number of crabs per area (n°ind/m^2) found (between 172 – 418 crabs /m^2) is comparable to other abundance values reported: 289 – 448 crabs/m^2 in the same study area (Afonso, 1996), 238 – 872 crabs/m^2 at Inhaca Island (Paula & Dray, 1995), and 48-564 crabs/m^2 in Dar es Salaam (Hartnoll, 1973).

Table 1. Comparisons of environmental parameters at Costa do Sol, Inhaca Is. and Dar es Salaam.

Locatily	Tidal level	Mean grain size	Organic matter content	Reference
Costa do Sol	3.5	Fine medium sand (2 ∅ – 4∅)	Low (< 4%)	Achimo, 2000
Inhaca Is.	3.1 *	Medium/fine sands (1 ∅ – 4∅)	Low	Guerreiro *et al.*, 1996
Dar es Salaam	3.2	Medium/fine sands (1.2 ∅ – 2.7 ∅)	Low	Hartnoll, 1973

* MacNae & Kalk, 1969

The similarity of environmental conditions in the field (such as tidal level, sediment median grain size and organic matter content) and predation pressure could explain the constancy of abundance numbers of *D. fenestrata* (Table 1).

In terms of crab mean abundance before and after the disturbance period at each area, no significant differences were found. This result could probably be explained by:

1. The well-reported migrating behavior of *Dotilla* (Macnae & Kalk, 1962; Hartnoll, 1973; Fishelson, 1983; Branch *et al*., 1995 and pers. obs.) following tidal movements, which can cause a rapid recolonization and recovering of the disturbed population; and
2. *D. fenestrata* digs burrows between 10-20 cm deep (Hartnoll, 1973; Afonso, 1996). As the high disturbance area is characterized by medium grain size sand particles (Afonso, 1996), it is very unlikely that a burrowed crab would suffer an impact resulting from trampling coming from the surface. Even juvenile crabs, which normally inhabit areas with a very superficial water table and do not excavate burrows, seemed less affected (Figure 6b).

Sampling station B of both the low and high disturbance areas showed a significant increase in biomass values after disturbance periods. This could be explained by the decrease of juveniles (Figure 6a) through migration (see below) in the low disturbance area. As Hartnoll (1973), Paula & Dray (1995) and Afonso (1996) showed, adults dominate intertidal high level areas. So, juveniles with wider carapace width migrate from the low to high intertidal levels possibly seeking better protection from fish predation and take advantage of the longer feeding time available (Hartnoll, 1973). Greater biomass at these two stations could also be caused by the period the sampling was conducted. Both post-disturbance samplings were done exactly at the full (high disturbance area) and new moon (low disturbance area) days. According to Afonso (1996) at these periods, *D. fenestrata* populations at Costa do Sol intertidal flats, reach their biomass peaks.

Paula & Dray (1995), found evidence that *D. fenestrata* recruitment at Inhaca Island, followed a lunar (monthly) periodicity, which could also explain juvenile abundance values differences in the low disturbance area (Figure 6a). They found that larger juveniles (3-mm carapace width) were common in new moon periods. These crabs could easily effectuate tidal migrations and explain the decrease in the number of juveniles at the low disturbance area.

This is the first study regarding human physical disturbance ever done in Mozambique. As so, there is much work to be done on the subject, especially if one takes in consideration the high tourism potential of Mozambique coastal areas. Further studies on population dynamics and reproduction of the soldier crab are needed, to better explain the variability of abundance and biomass in relation to environmental variables and endogenic cycles. There is also, a need to study the influence of human trampling right after the disturbance takes place, thus, eliminating the effects of the tidal migration and recovery of the affected crab population.

ACKNOWLEDGEMENTS

We would like to acknowledge with thanks the following Department of Biological Sciences – UEM Biology course students for their help during fieldwork: Alice Costa, Carlos Litulo, Cristina Louro, Daniela Abreu, Eduardo Videira and Vanessa Cabanelas. Dr. Mark Whittington and Hermes Pacule are also acknowledged for their criticism and constructive comments, which improved earlier drafts of the manuscript. We are also grateful to Tânia Pereira and Domingos Gove for overall support and Custódio Boane, Alberto Sitoe and Maurício Lipassula for making laboratory facilities available. Finally we want to thank DANIDA and the Center for Sustainable Development of the Coastal Zones (Xai–Xai) for funding and logistic support.

REFERENCES

Afonso, A. (1996). *Estudo de alguns aspectos eco-etológicos do caranguejo* Dotilla fenestrata *na Praia do Bairro Triunfo, Maputo*. Tese de Licenciatura. 56 pp. Maputo, Universidade Eduardo Mondlane.

Bally, R. & C. L. Griffiths (1989). Effects of human trampling on an exposed rocky shore. *International Journal of Environmental Studies*, 34: 115–125.

Bandeira, S. O. (1995). Marine botanical communities in Southern Mozambique: Sea grass and seaweed diversity and conservation. *Ambio*, 24: 506–509.

Beauchamp, K. A. & M. M. Gowing (1982). A quantitative assessment of human trampling effects on a rocky intertidal community. *Marine Environmental Research*, 7: 279–293.

Branch, G. M., C. L. Griffiths, M. L. Branch & L. E. Beckley (1995). *Two oceans – A guide to the marine life of Southern Africa*. 359 pp. Cape Town, David Philip.

Brosnan, D. M. & L. L. Crumrine (1994). Effects of human trampling on marine rocky shore communities. *Journal of Experimental Marine Biology and Ecology*, 177: 79–97.

Brown, P. J. & R. B. Taylor (1999). Effects of trampling by humans on animals inhabiting coralline algal turf in the rocky intertidal. *Journal of Experimental Marine Biology and Ecology*, 235: 45–53.

de Boer, W. F. & F. A. Longamane (1996). The exploitation of intertidal food resources in Inhaca Bay, Mozambique, by shorebirds and humans. *Biological Conservation*, 78: 295–303.

Fernandes, A., M. T. Murta, A. Manuel, I. Amado & Z. Abixai (1993). Poluição na Baía de Maputo. *Revista Médica de Moçambique*, 4 (2): 17–22.

Fernandes, A. (1996). Poluição costeira: Factos e figuras. In: Dias, D., P. Scarlet, J. Hatton & A. Macia (eds). *O papel da investigação na gestão costeira da zona costeira: Proceedings do workshop*. Maputo, 24-25 Abril. 75–81 pp. Maputo, DCB/UEM.

Fishelson, L. (1983). Population ecology and biology of *Dotilla sulcata* (Crustacea, Ocypodidae) typical for sandy beaches of the Red Sea. In: MacLachlan, A. & T. Erasmus (eds.). *Sandy beaches as ecosystems*. 643–654 pp. The Hague, Dr W. Junk Publishers.

Ghazanshahi, J., T. D. Huckel & J. S. Devinny (1983). Alteration of southern California rocky shore ecossystems by public recreational use. *Journal of Environmental Management*, 16: 379–394.

Gujral, L. M. F. (1995). *Alguns aspectos da ecologia e biologia da* Holothuria scabra *na Ilha da Inhaca*. Tese de Licenciatura. 49 pp. Maputo, Universidade Eduardo Mondlane.

Hartnoll, R. G. (1973). Factors affecting the distribution and behaviour of the crab *Dotilla fenestrata* on East Africa shores. *Eastuarine and Coastal Marine Science*, 1: 137–152.

Kalk, M. (ed.) (1995). *A natural history of Inhaca Island, Mozambique*. Third Edition, 395 pp. Johannesburg, Witwatersrand University Press.

Keough, M. J. & G. P. Quinn (1998). Effects of periodic disturbances from trampling on rocky intertidal algal beds. *Ecological Applications*, 8: 141–161.

Lercaria, D. & O. Defeo (1999). Effects of freshwater discharge in sandy beach populations: The mole crab *Emerita brasiliensis* in Uruguay. *Estuarine, Coastal and Shelf Science*, 49: 457–468.

Longamane, F. A. (1995). *Exploração das áreas entre-marés pela população humana no saco da Ilha da Inhaca*. Tese de Licenciatura. 57 pp. Maputo, Universidade Eduardo Mondlane.

Macnae, W. & M. Kalk (1962). The fauna and flora of sand flats at Inhaca Island, Mozambique. *Journal of Animal Ecology*, 31: 93–128.

Paula, J. & T. Dray (1995). Biological and ecological aspects of the populations of the crab *Dotilla fenestrata* (Hilgendorf, 1869) (Brachyura, Ocypodidae) in the tidal flats of Inhaca Island. In: Hemminga, M. A. (coordinator). *Interlinkages between Eastern African coastal ecosystems*. EEC Contract N° TS3*-CT92-0114. Final Report, December 1995. 254–263 pp.

Pereira, T. I. F. C. (1998). *Estudo dos concheiros na Ilha da Inhaca: Avaliação do impacto humano sobre as áreas entre-marés*. Tese de Licenciatura. 53 pp pp. Maputo, Universidade Eduardo Mondlane.

Povey, A. & M. J. Keough (1991). Effects of trampling on plant and animal populations on rocky shores. *Oikos*, 61: 355 – 368.

Raffaelli, D. & S. Hawkins (1996). *Intertidal ecology*. 356 pp. London, Chapman & Hall.

Ruwa, R. K. (1996). Intertidal wetlands. In: MacClanahan, T. R. & T. P. Young (eds.). *East African ecosystems and their conservation*. 101–130 pp. Oxford, Oxford University Press.

Schiel, D. R. & D. I. Taylor (1999). Effects of trampling on a rocky intertidal algal assemblage in southern New Zealand. *Journal of Experimental Marine Biology and Ecology*, 235: 213–235.
Stark, J. S. (1998). Heavy metal pollution and macrobenthic assemblages in soft sediments in two Sydney estuaries, Australia. *Marine and Freshwater Research*, 49: 533–540.
Zar, J. H. (1999). *Biostatistical analysis*. Fourth Edition, 663 pp. New Jersey, Prentice-Hall.