

Spatial patterns in parasite infection support the multi-stock hypothesis for South African sardine *Sardinops sagax*

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Introduction

The possible multiple-stock nature of the South African sardine population has been the focus of recent research on this species, and a document describing spatial variation in several characteristics of sardine from around the South African coast and providing the biological basis for the hypothesis of multiple sardine stocks was tabled at the 2011 International Stock Assessment Workshop (van der Lingen 2011). Amongst other things, that document briefly described the use of parasites as biological tags in population structure studies and reported spatial variation in the prevalence of infection (percentage of sample infected) of sardine by a “tetracotyle” type metacercarian parasite and considered (but not yet definitively identified) to be of the genus *Cardiocephaloides*. Examination of a total of 484 sardine taken mostly from research survey samples collected between Hondeklip Bay on the west coast and Durban on the east coast showed a discontinuous distribution in infection, with fish from the west coast showing substantially higher prevalence of infection rates and higher mean infection intensities (number of parasites.infected fish⁻¹) than those from the south or east coasts. In addition, infection in sardine off the west coast appeared to occur at a smaller size than in fish from the south or east coasts (Fig. 1; van der Lingen 2011). Those data were considered inconsistent with the hypothesis of a single-stock in which biological parameters are spatially-invariant (Smith *et al.* 2011) and hence taken as support for the sardine multi-stock hypothesis. This document provides an update on further work examining South African sardine population structure using this parasite biotag.

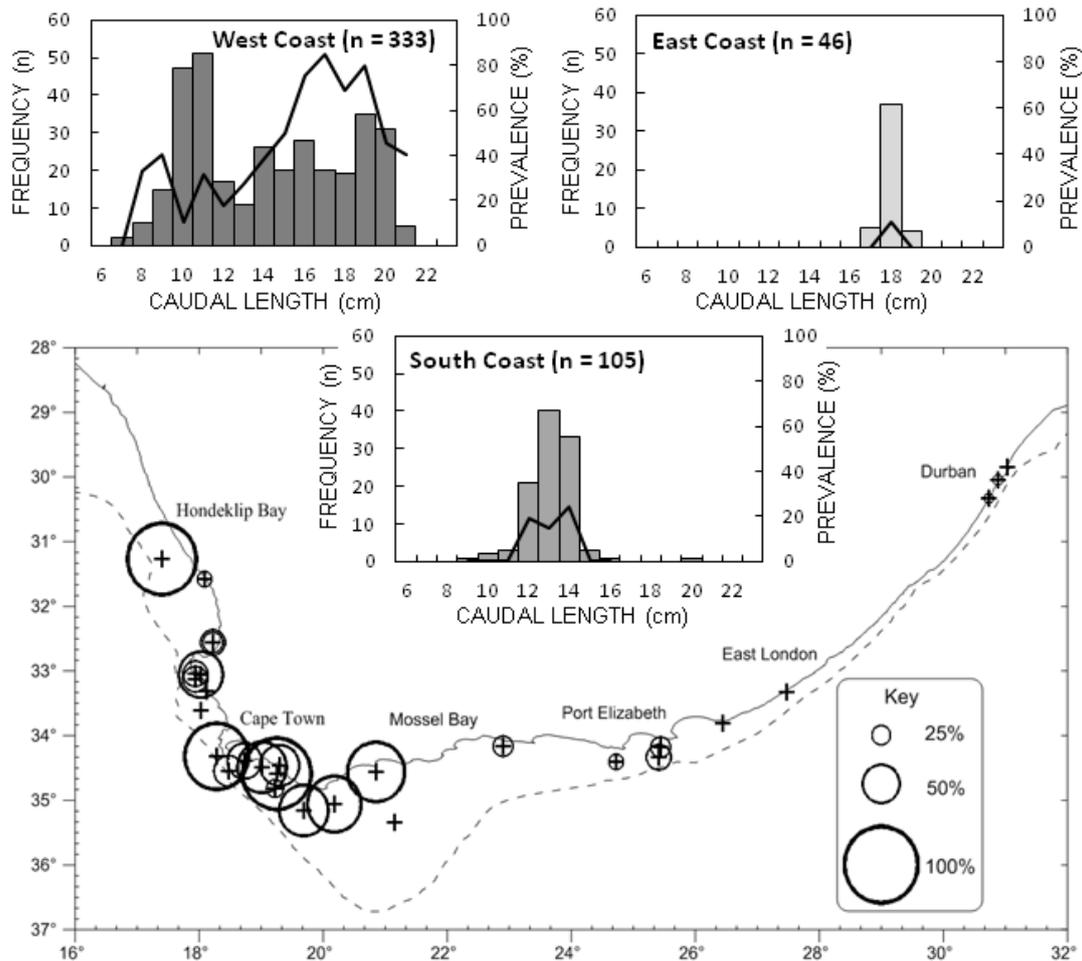


Figure 1: Sample locations (crosses) and prevalence (% of sample; circles) of infection by the parasite *Cardiocephaloides* sp. of sardine (map); and length frequency distribution (n; histograms) and prevalence as a function of length (%; line) for sardine from the west (<21°E), south (21–28°E) and east (>28°E) coasts respectively (from van der Lingen 2011).

Recent Work

Further studies of the occurrence of the “tetracotyle” type metacercarian parasite in sardine have been conducted. Weston *et al.* (2013) assessed spatial and temporal variation in “tetracotyle” type metacercariae infection by examining a total of 1 318 adult fish collected throughout the year from commercial purse-seine catches taken from the putative western (n = 641) and southern (n = 677) sardine stocks over the period March 2011 to December 2012. Those authors recorded infection prevalence (%), mean infection intensity and mean parasite abundance (number of parasites.fish⁻¹) for each sample, and used generalised linear modelling to assess the dependency of these three indices on putative stock, season, year, sardine caudal length (CL), and their possible interactions. A binomial distribution was assumed for the prevalence data and a negative binomial distribution for infection intensity

and parasite abundance. Significant models were derived for all three parasite indices (Mean abundance pseudo $r^2 = 0.30$; Mean infection intensity pseudo $r^2 = 0.29$; Prevalence pseudo $r^2 = 0.17$) and all factors contributed significantly to all models. Putative stock was the most significant contributor to observed deviance in mean parasite abundance and mean infection intensity, and the second-most important contributor (only slightly less important than year) to (Weston *et al.* 2013) in prevalence of infection. Detailed results from the GLM for mean abundance are shown in Table 1.

Table 1: Outputs from the GLM for mean parasite abundance (Weston *et al.* 2013).

Factor	Residual DF	Residual Deviance	Δ Deviance	p-value	% Deviance explained
Null	1315	1810.1			
Putative stock	1314	1609.5	200.547	<0.001	36.3
Season	1311	1519.7	89.828	<0.001	16.3
Year	1310	1422.3	97.429	<0.001	17.6
Log(CL)	1309	1324.7	97.602	<0.001	17.7
Stock:Season	1306	1277.8	46.915	<0.001	8.5
Stock:Log(CL)	1304	1257.6	20.182	<0.001	3.7

Sardine from the putative western stock had significantly higher parasite loads than those from the putative southern stock, with temporally-averaged parasite abundance for a fish of 18.2 cm CL (normalised length) ranging from 3-7 parasites.fish⁻¹ for the former compared to 1-4 parasites.fish⁻¹ for the latter (Fig 2a). Fish from both stocks showed seasonality in infection, although the pattern differed between the two with peak infection in winter in fish from the putative western stock and in spring in the putative southern stock (Fig 2a). Parasite loads were higher in 2012 compared to 2011 for fish from both putative stocks (Fig. 2b). Infection intensity increased with fish size and hence presumed age for all fish but the pattern differed between sardine from the two stocks, with those from the putative western stock showing infection at a smaller size than those from the south (Fig. 2c). Despite observed seasonal and interannual variation these results clearly demonstrate the dominant spatial signal in parasite loads, and support the hypothesis of discrete western and southern sardine stocks (Weston *et al.* 2013).

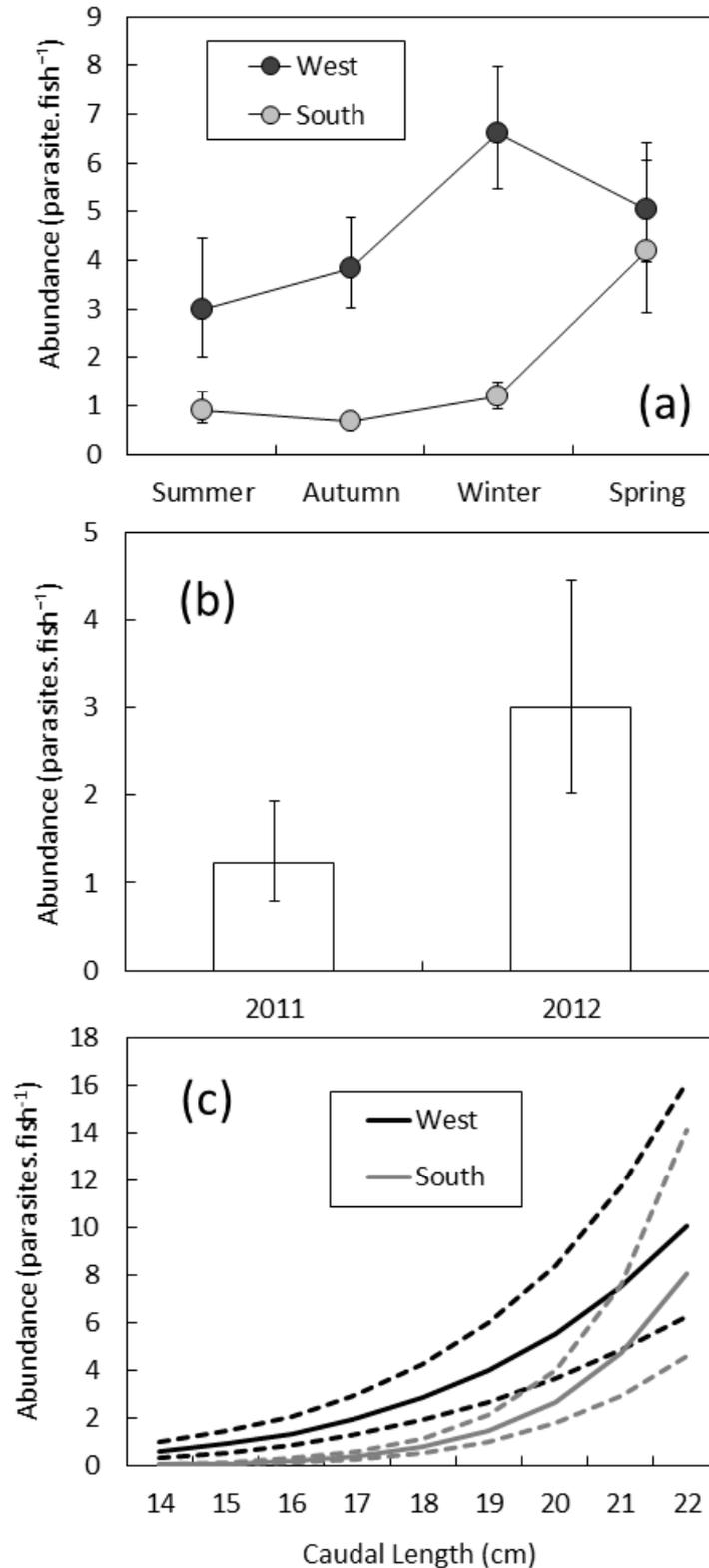


Figure 2: Predicted abundance (parasites.fish⁻¹ ± 95% CI) of “tetracotyle” type metacercariae in *Sardinops sagax* from commercial catch samples in terms of (a) Stock and Season (normalised for a fish of 18.2 cm CL); (b) Year (normalised for a fish of 18.2 cm CL); and (c) caudal length for fish from the putative western and southern stocks (from Weston *et al.* 2013).

Determination of infection by the “tetracotyle” type parasite of sardine from research survey samples has continued, and data from a large number (almost 3 500) of fish from 130 locations off South Africa, as well as 174 fish from the northern Benguela off Namibia have now been collected over the period 2010-2012 (van der Lingen *et al.* in preparation). These data have yet to be subjected to detailed statistical analysis but preliminary exploration has confirmed the pattern of spatial variability in “tetracotyle” type metacercariae infection of sardine in the Benguela system. No infected sardine from Namibia were recorded, and fish from the putative eastern stock off the KZN coast ($n = 388$) showed a very low (1.8%) prevalence of infection. Prevalence levels of sardine from the putative western and southern stocks (separated at Cape Agulhas; 20°E) were similar (22.5% and 17.2%, respectively), but analysis of mean parasite abundance by size shows a clear spatial pattern of declining abundance eastwards for all three size classes (Fig. 3). Few infected juvenile (<12.5 cm CL) sardine were found, and of the 43 locations where fish of this size were collected only 10 had infected fish, and seven of these were to the west of Cape Agulhas (Fig. 3a). Sub-adult (12.5-16.5 cm CL) and adult (>16.5 cm CL) sardine also showed strong gradients in mean parasite abundance, values being highest off the west coast and western part of the south coast, low to moderate off the remainder of the south coast, and close to zero for fish off the east coast (Fig. 3b, c).

Conclusions

A preliminary survey of parasites infecting South African sardine was conducted by Reed *et al.* (2012) in order to assess the potential of using parasites as biological tags for stock discrimination and to identify a possible biotag or biotags. Those authors examined 102 sardine and recorded seven parasite taxa, and suggested that digenean metacercariae parasites of the “tetracotyle” type that were found only in the humours of sardine eyes had the highest potential as a biotag. That parasite was nominated because of an observed discontinuous distribution in infection, site-specificity in the host and a likely long life span, all of which are established criteria for a good parasite biotag (MacKenzie and Abaunza, 2005). Subsequent examination of a substantial number (almost 5 000) of sardine collected from commercial catch and research samples around South Africa have clearly shown spatial variation in infection of sardine by this parasite, and statistical analysis of data from

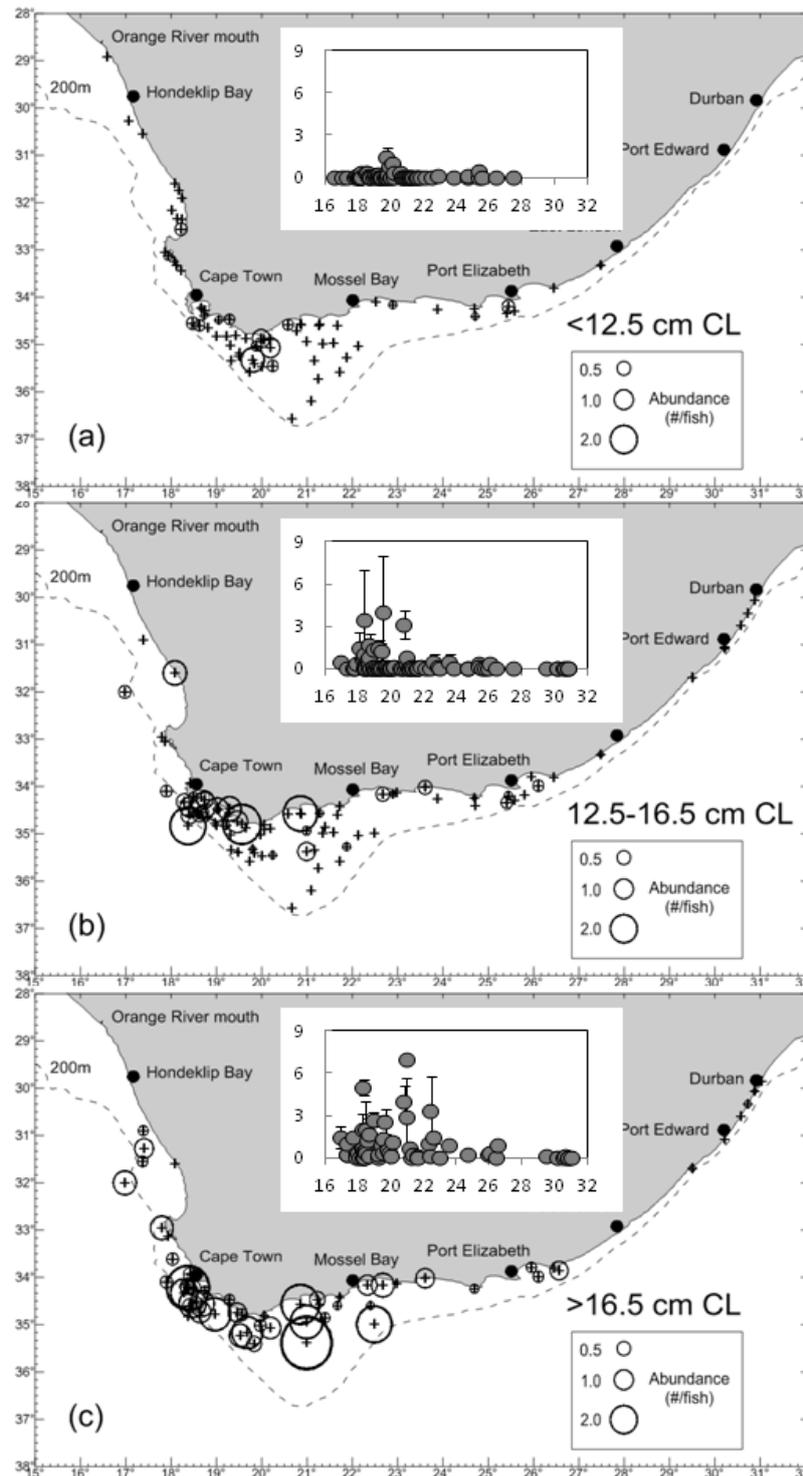


Figure 3: Mean abundance (parasites.fish⁻¹; black circles with diameter proportional to abundance) per sample for sardine of (a) <12.5 cm CL (approximately 0+ years old), (b) 12.5-16.5 cm CL (approximately 1+ years old), and (c) >16.5 cm CL (approximately 2+ years old) around the South African coast. Black crosses show sample locations and the inserts on each map show a scatterplot of mean abundance (y-axis; number per fish) against longitude (x-axis; from van der Lingen *et al.* unpublished data).

commercial catch samples that assessed the effect of putative stock, season, year and fish size has demonstrated that putative stock is the strongest determinant of variability in infection of sardine by this parasite. These results are incompatible with the single-stock hypothesis and therefore add further support to the sardine multi-stock hypothesis.

References

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