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Cover image: Woman collecting ascideans at Ponta Mazondue, Inhaca Island, Mozambique (© José Paula, 2005)

Reproductive biology of the beaked clam *Eumarcia paupercula* (Bivalvia: Veneridae) from Maputo Bay, Mozambique

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Abstract
The beaked clam *Eumarcia paupercula* (Holten 1802) (Bivalvia: Veneridae) is an important fishery resource for local artisanal fishers in Maputo Bay. Its annual reproductive cycle was described by following seasonal fluctuations in the condition index of the population occupying a tidal flat, and by analysing fresh gonad smears to confirm that changes in condition were, in fact, due to gonad state. Macroscopic gonad observations and changes in body condition confirmed that *E. paupercula* is a year-round breeder with three spawning peaks, with the major spawning periods occurring during summer. The spawning pattern found in this study is similar to other clams inhabiting similar tropical ecosystems.

Keywords: Reproductive activity, condition index, *Eumarcia paupercula*, Maputo Bay, venerid clam

Introduction
The stages and frequency of gonadal maturation in clams varies among species and are typically dependent on environmental conditions (Laruelle *et al.*, 1994; Adkins *et al.*, 2016). Various studies on reproductive patterns have shown that clams exhibit long spawning periods over the year (Narasimham *et al.*, 1988; McLachlan *et al.*, 1996; Tirado and Salas, 1999; Denadai *et al.*, 2015). This is particularly true in venerids, in which spawning typically peaks one to three times a year (Laruelle *et al.*, 1994; Jagadis and Rajagopal, 2007; Luz and Boehs, 2011).

The venerid clam *Eumarcia paupercula* inhabits sandy and muddy bottoms, and it is usually found 2–3 cm below the surface in the intertidal zone. It is one of the most important commercial clam species in Maputo Bay, Mozambique (Scarlet, 2005; Rosendo, 2008; Vicente and Bandeira, 2014). Effective regulation of this fishery requires understanding of the reproductive cycle of *E. paupercula*, particularly its spawning time. This is because most of the management measures applied in fisheries are related to the capacity of a species to reproduce and recruit to compensate for its removal by fishing. This study represents the first attempt to describe the reproductive activity of the beaked clam, *E. paupercula*, inhabiting Maputo Bay.

Methods
Study area
Maputo Bay is located in southern Mozambique, between 25°55’ and 26°10’S, and 32°40’ and 32°55’ E (Fig. 1). The total area of the Bay is 1280 km², of which approximately 774 km² constitutes the sub-littoral zone, while the remainder is equally divided between intertidal areas and sand dunes (Lencart *et al.*, 2010). Sampling for *E. paupercula* took place at Costa do Sol beach, an intertidal sandflat that is the major fishing area in Maputo Bay and a major source of harvested *E. paupercula*.

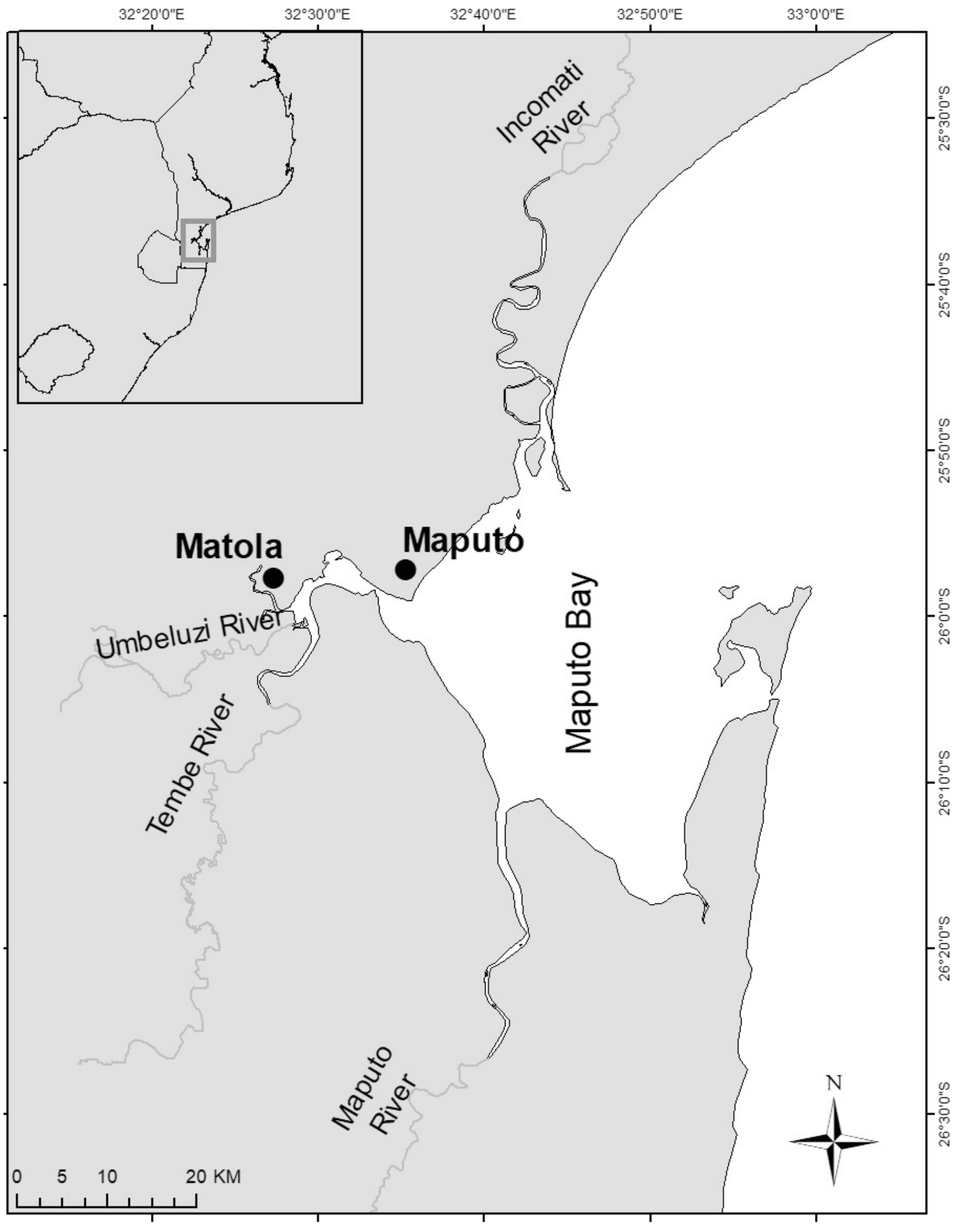

Figure 1. Maputo Bay, with rivers discharging into the Bay and main cities marked as black dots (Matola and Maputo).

Sample collection

Sixty clams measuring ≥ 20 mm in length were collected during low spring tides each month between November 2012 and April 2014. Thirty of these clams were used for gonad smear observations and macroscopic gonad analysis, and the other 30 for measuring the condition index (CI). In addition, three replicate water temperature (˚C) and salinity measurements were made *in situ* on each day of sampling. A hand-held digital thermometer and refractometer were used to record temperature and salinity, respectively. Total monthly rainfall data for the study period were obtained from the Mozambican National Institute of Meteorology, Maputo.

Description of reproductive cycle

Two methods were used to describe the reproductive activity of *E. paupercula*. The first was a measure of condition index, expressed as the fluctuation in flesh dry weight (FDW) of a standard sized (30 mm shell length) individual. The changes in FDW of the standard 30 mm individual were calculated from monthly length/condition regressions of 30 individual clams, which were fitted using a power function ($FDW = aL^b$). The weight of a standard sized individual was determined using each monthly regression. Regressions were fitted using the SPSS 22.0 statistical package.

The second method was based on a macroscopic examination of gonad maturation for 30 clams in which the reproductive state of each clam was scored following a visual scale of stages, developed from a combination of scales defined for other venerids (Shafee and Daoudi, 1991; Baron, 1992; Jagadis and Rajagopal, 2007), as follows:

Stage 1 – Inactive (INA): the gonad is barely discernible macroscopically and tissue is limited to a thin translucent and colourless layer. In most individuals, sex is indeterminate at this stage.

Stage 2 – Maturing (MAT): whitish gonad clearly observed. The space occupied by the gonad is small and the digestive diverticula (dark green to black) can be seen once a clam is opened.

Stage 3 – Ripe (RIP): gonad is cream coloured, has reached the maximum size and become turgid, covering a major part of the digestive diverticula and diffusing to the foot area. The release of reproductive material is rapid when the gonad is pricked with a needle.

Stage 4 – Partial Release (PR): gonad is cream coloured and has a loose consistency.

Stage 5 – Total Release (TR): colour of gonad becomes light cream to white in colour. Sex remains identifiable when cutting the gonad tissue. At this stage, all mature gametes have been released.

Sexual products were also taken and sex determined by performing a smear and observing this at 400 X magnification, and sex ratio was presented as percentages of males and females. To determine if the sex ratio differed from 1:1, a Chi-square test (χ^2) was conducted each month.

Data Analysis

Pearson's correlation was used to compare relationships between environmental variables and CI. One-way analysis of variance (ANOVA) followed by a post hoc Tukey test, was used to test for significant differences in CIs among the 18 study months. The correlation between environmental factors and reproductive

Table 1. Monthly regression equations of length-weight relationships. FDW = Flesh Dry Weight (g), L = length (mm), a = intercept and b = slope at α = 0.05.

Month-Year	Regression Equation ($FDW = aL^b$)	FDW (30 mm individual)
N – 12	$y = 0.001x^{2.68}$	6.4
D – 12	$y = 0.037x^{1.41}$	4.4
J – 13	$y = 0.002x^{2.33}$	5.6
F – 13	$y = 0.053x^{1.39}$	6.1
M – 13	$y = 0.082x^{1.32}$	7.5
A – 13	$y = 0.024x^{1.66}$	6.8
M – 13	$y = 0.001x^{2.64}$	6.3
J – 13	$y = 0.002x^{2.39}$	6.5
J – 14	$y = 0.004x^{2.19}$	6.6
A – 13	$y = 0.0001x^{3.3}$	5.6
S – 13	$y = 0.0001x^{3.21}$	5.6
O – 13	$y = 0.0002x^{3.05}$	6.3
N – 13	$y = 0.087x^{1.23}$	5.8
D – 13	$y = 0.009x^{1.88}$	5.1
J – 14	$y = 0.041x^{1.46}$	5.8
F – 14	$y = 0.008x^{1.95}$	6.5
M – 14	$y = 0.001x^{2.62}$	7.7
A – 14	$y = 0.004x^{2.21}$	6.0

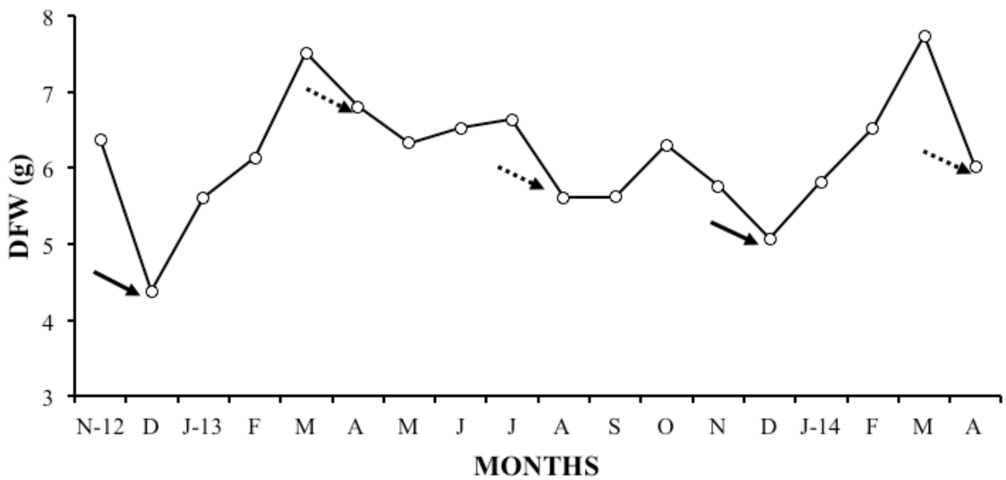

Figure 2. Average monthly changes in condition (n = 30) of *Eumarcia paupercula* at Maputo Bay from November 2012 to April 2014. Solid and doted arrows indicate major and minor spawning peaks, respectively at α = 0.05.

cycles was assessed using changes in CI as an indicator of spawning events. All statistical analyses were performed in SPSS 22.0.

Results

The mean sex ratio of males to females in the 18 monthly samples was 275:253, (12 indeterminate). The overall sex ratio did not differ significantly from 1:1 (x^2 = 0.60, df = 1, P = 0.44) over the 18 months; however, it differed from unity during three individual months, namely November 2012 (19:11), July 2013 (20:10), and August 2013 (19:11).

The monthly equations relating FDW to shell length, and the FDWs of standard sized (30 mm) individuals, are presented in Table 1. Changes in FDW in a standard sized individual (30 mm shell length) over the study period are presented in Fig. 2. The FDW dropped in December 2012 and increased rapidly until March 2013, after which a slight drop was observed. Significant drops in FDW (F = 25.45, P < 0.05) were observed during December 2012, August and December 2013, and April 2014.

The monthly distributions of gonad stages are illustrated in Fig. 3. Ripe individuals were present during all sampling months, although they occurred in more than 50% of individuals in the sample only during four months (November and December 2012, and August and November 2013). These periods preceded the

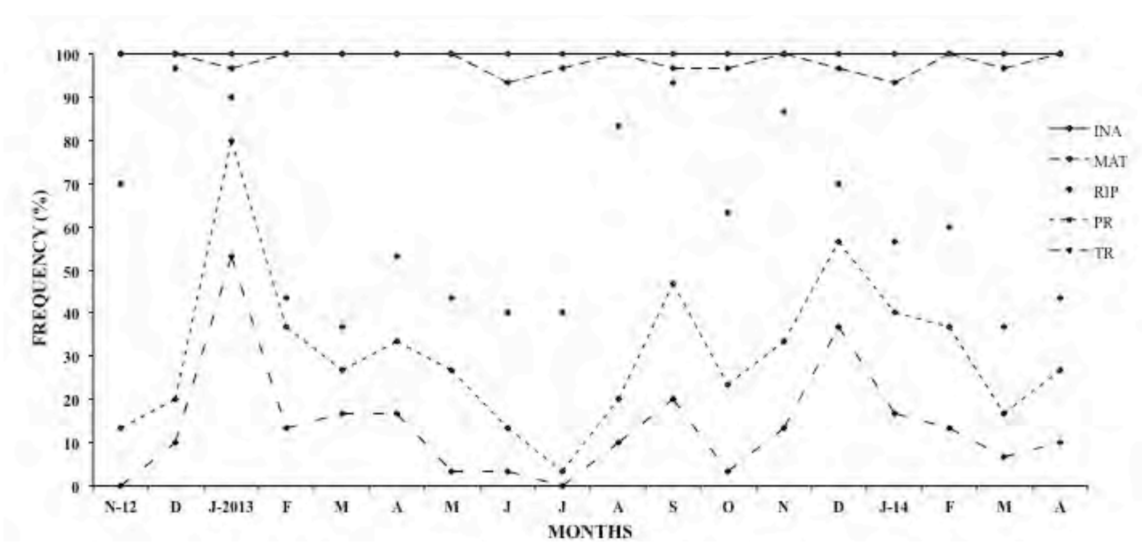

Figure 3. Percentages of mature *Eumarcia paupercula* in Maputo Bay showing various stages of gonad maturation as derived from macroscopic observations of gonads. INA - indeterminate; MAT - Maturing; RIP - Ripe; PR - Partial Release; and TR - Total Release stages.

months in which the highest percentages of individuals releasing gametes (individuals in PR and TR phases) were recorded. Similarly, individuals in maturing stages (MAT) were present throughout the sampling period, comprising over 50% of the sample towards the the end of summer (February and March 2013) and the greater part of winter (April – July 2013). Over the course of the 18 sampled months, inactive or sex indeterminate individuals (INA) were only recorded in eight months, and they always represented less than 10%.

The mean monthly sea temperature and salinity readings in the study area are presented in Fig. 4. Monthly temperature recorded during sampling (mean ±SD) ranged from a minimum of 22.1±0.26⁰C in August 2013 to a maximum of 30.9±1.11⁰C in January 2014. The average salinity recorded during sampling ranged from a low of 33.0±0.8 in November 2013 to a high of 38.2±0.5 in September 2013. There was no rainfall in June and July 2013, nor in March and April 2014, and the maximum monthly rainfall (262.1 mm) throughout the study period was recorded in January 2013 (Fig. 5). Pearson's correlation analysis indicated non-significant correlations between CI of the standard individual of 30 mm and all of the environmental drivers analysed, namely temperature (r = 0.022, P > 0.05), rainfall (r = -269, P > 0.05), and salinity (r = 0.036, P > 0.05).

Discussion

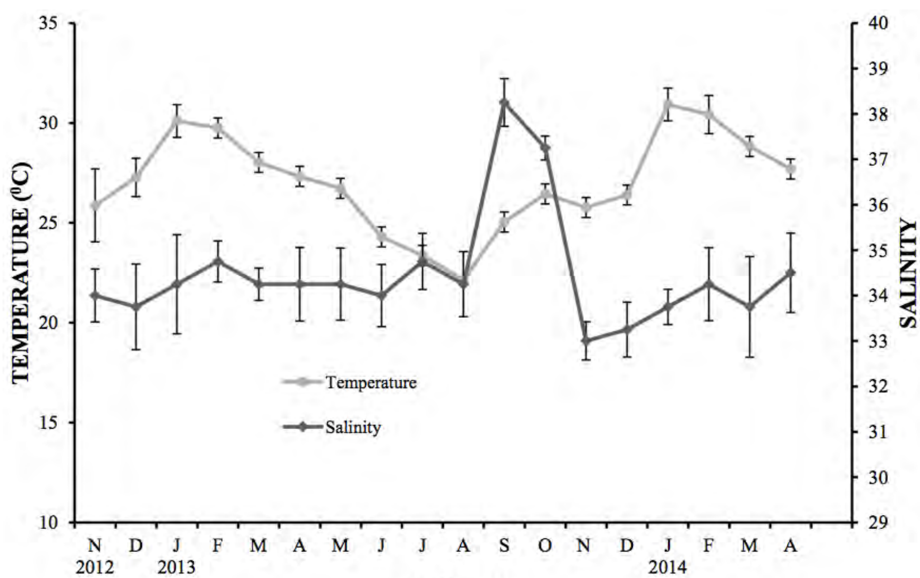

Figure 4. Monthly mean (±SD) water temperature (0C) (black line) and salinity (grey line) in Maputo Bay from November 2012 to April 2014.

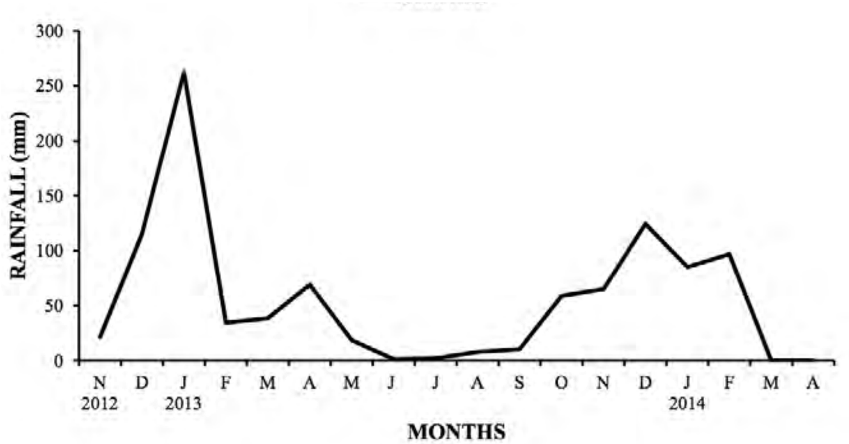

Figure 5. Monthly rainfall (mm) recorded for Maputo Bay from November 2012 to April 2014.

Sex ratio

Although reproductive cycles of venerids have been studied for tropical and temperate waters globally, the majority of these studies have taken place in the northern hemisphere, and the present study is the first for *E. paupercula*. Table 2 shows reproductive characteristics of venerids from the literature. From 8 other studies (on 6 different species) that presented sex ratio data, all reported sex ratios as being close to parity (the M:F ratio varying from only 1:1 to 1: 1.3). This means that regardless of species and study site, the sex ratio of venerids is close to 1:1. Nevertheless, it is of interest to note that some minor variation in sex ratio with latitude was reported for *Marcia opima* from India by Suja and Muthiah (2007).

Reproductive cycle

Both methods used to quantify the reproductive cycle of *E. paupercula* detected three spawning peaks. The major spawning occurs in December-January, and two minor events occur in March-April, and August-September. PR individuals were found during all 18 months in which samples were collected, suggesting that *E. paupercula* undergoes partial spawning; meaning that individuals only partially release mature gametes. It was considered that a spawning peak occurred when the sum of individuals in TR and PR stages was ≥ 50%. In addition, indeterminate individuals may be added to the group of animals considered to have already spawned, as a complete spawning would have recently occurred. Consequently, September 2013 was also considered a spawning peak, and the drop in the condition in the previous month (August 2013) supports this. Although TR and PR individuals were present throughout the sampling period, their highest percentage occurrence was in summer. Peak spawning during summer months likely explains the accumulation of reserves during the winter, since these are transformed into reproductive material prior to gamete releases in the summer. Table 2 shows the seasonal spawning peaks for several venerid species, and while some species spawn during winter, most tropical and subtropical clams follow a similar spawning pattern to that seen in this study.

When venerids from tropical and subtropical areas are analysed, it is apparent that species found furthest from the tropics spawn two or three times a year for prolonged periods (Jayabal and Kalyani, 1987; Barreira and Araujo, 2005; Suja and Muthiah, 2007; Luz and Boehs, 2011), while others exhibit year-round spawning (Jagadis and Rajagopal, 2007; Denadai *et al.*, 2015). Thus, the spawning pattern of *E. paupercula* in Maputo Bay is similar to those of most other tropical and subtropical clam species (but see Denadai *et al.*, 2015). The limited number of species from tropical-subtropical areas referred to in this table reflects a lack of studies on venerids from these regions.

Reproductive cycle in relation to environmental parameters

No significant correlation between reproductive activity and any of the environmental parameters measured was found. The effect of salinity on reproduction of bivalves is not well understood. For most of the study period, salinity was between 32 and 35 and remained stable at levels considered normal for coastal marine habitats, with insufficient variation to affect animal physiology. This fact has been confirmed for *Austrovenus stutchburyi*, which maintained high CI even at salinities <20 (Adkins *et al.*, 2016).

There seemed to be a drop in condition following a rise of temperature, as recorded in January 2013, or when high temperatures were recorded, as in December 2013. This also occurred when there was a decline in temperature (August and September 2013). However, in June 2013, the PR and TR stages accounted for only 13% of individuals, and INA for 7%. An absence of a relationship between temperature and reproductive cycles was also recorded for the year-round spawning venerid *Marcia opima* by Suja and Muthiah (2007). Generally, in tropical ecosystems, where fluctuations of temperature are minimal, bivalves have continuous reproductive cycles.

Rainfall is often indirectly considered as a driving factor of reproductive cycles in clams inhabiting tidal flats, because of its ability to reduce salinity (Riascos and Jose, 2006; Nakamura *et al.*, 2010; Baek *et al.*, 2014). The total monthly rainfall recorded for each month in the present study was considered insufficient to actually lower levels of salinity, which could have, for example, caused spawning to cease.

All in all, the reproductive season of *E. paupercula* in Maputo Bay is characterized by a long spawning season with three annual peaks. The presence of only a few individuals in indeterminate stages during sampling may be indicative of a very short resting period before recuperation. Literature discussing the beaked clam *E. paupercula* is limited, particularly with regards to the management of stocks and understanding the reproductive cycle. In Maputo Bay this species is being heavily exploited for food, emphasising that it is important to start considering the implementation of management practices. These could be based on the reproductive pattern, which seems to be linked to environmental factors during the summer such as increased food availability and elevated temperatures, and which may regulate spawning intensity.

Table 2. Some reproductive characteristics of venerids globally. The latitude of each study site is presented in the column “Location”. Species have been named according to references, and synonyms were treated separately. Cells with a dash (-) denote an absence of data from the source.

Species	Location	Temperature (°C)	Sex Ratio (M:F)	Spawning events: Peaks	Reference
Anomalocardia brasiliana	Brazil	-	1:1.2	Two: Feb – Apr; Jul - Oct	Barreira & Araujo, 2005
A. brasiliana	Brazil	20 – 35	1:1.2	Two: Jan – May; Sep - Nov	Luz & Boehs, 2011
Cyclina sinensis	China (37°84’ N)	2.0 – 30.0	-	One: Aug	Yan *et al.*, 2010
Eumarcia paupercula	**Mozambique (25°54’ S)**	**22.2 – 30.9**	**1:1**	**Year-round: Apr-May; Sep; Nov – Feb**	**This study**
Gafrarium tumidum	India (08°35’ - 09°25’ N)	-	1:1.3	Year-round: Nov; Apr	Jagadis & Rajagopal, 2007
M. opima	India (08°45’ N)	26.0 – 32.3	1:1	Two: May – Jul; Sep – Dec	Suja & Muthiah, 2007
M. opima	India (09°28’ N)	24.0 – 34.0	1:0.7	Two: Mar – May; Sep – Dec	Suja & Muthiah, 2007
Mercenaria mercenaria	USA (41°67’ N)	17.5 – 25.5	-	One: June	Rice & Goncalo, 1994
M. mercenaria	USA (38°.77’ - 39°06’ N)	-	-	One: Jul - Sep	Marroquin-Mora & Rice, 2008
M. mercenaria	USA (40°55’ - 41°01’ N)	-	-	One: May Sep	Doall *et al.*, 2008
Meretrix meretrix	India (11°17’ N)	-	1:1	One long: Feb – Sep	Jayabal & Kalyani, 1987
Ruditapes decussatus	UK (47°40’ N)	-	-	One: Jul – Oct	Laruelle *et al.*, 1994
R. decussatus	France (43°23’ N)	-	-	Two: Jun – Aug	Borsa & Millet, 1992
R. philippinarum	Ireland (54°33’ N)	7.1 – 18.5	1:1.2	One: Jun – Sep	Drummond *et al.*, 2006
R. philippinarum	UK (47°30’ - 48.20 N)	-	-	Three: May, Jul-Aug	Laruelle *et al.*, 1994
R. philippinarum	France (44°68’ N)	4 – 28	-	One: Sep-Oct	Robert *et al.*, 1993
R. philippinarum	Spain (42°68’N)	-11 – 22	-	Two: Apr – Aug; Aug – Nov[2]	Rodrıguez-Moscoso *et al.*, 1992
Tapes philippinarum	Russia (42°30’ - 43°53’ N)	-1.0 – 25.0	1:1	One: Jul – Aug	Ponurovsky & Yakolev, 1992
Tawera gayi	Argentina (54°50’S)	3.4 – 8.2	1:1.1	One: Oct	Morriconi *et al.*, 2007
Venux nux	Spain (36°56’ N)	12.0 – 16.0	1:1	Year-round: Jun – Jul	Tirado *et al.*, 2011
V. nux	Spain (36°34’ N)	13.0 – 21.8	1:1	Year-round: Apr – May	Tirado *et al.*, 2011

[1]Parasite infection affected sex ratio analysis over sampling

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