

Differences in reproductive strategies between two co-occurring mullets *Mugil curema* Valenciennes 1836 and *Mugil liza* Valenciennes 1836 (Mugilidae) in a tropical bay

R.J. ALBIERI¹, F.G. ARAÚJO^{1,2} and W. UEHARA¹

¹ Universidade Federal Rural do Rio de Janeiro, Laboratório de Ecologia de Peixes, km 47, Antiga Rodovia Rio-São Paulo, 23851-970 Seropédica, RJ, Brazil

Received 25 August 2009, accepted 25 May 2010

The female reproductive strategies of *Mugil curema* Valenciennes 1836 and *Mugil liza* Valenciennes 1836 occurring in a tropical bay in southeastern Brazil were found to differ. Gonadosomatic index values and macroscopic staging of gonads showed that *M. curema* spawning took place between August and January, while *M. liza* spawning occurred between May and August. *M. curema* spawning began just before the rainy season, whereas *M. liza* spawned during the dry season. Estimates of absolute fecundity (F) and relative fecundity (RF) were significantly greater ($P < 0.01$) for *M. liza* (mean F = $308 \times 10^4 \pm 104 \times 10^3$; mean RF = 1396.42 ± 67.02) than for *M. curema* (mean F = $415 \times 10^3 \pm 32 \times 10^3$; mean RF = 750.54 ± 40.52). Oocyte diameters were slightly greater in *M. liza* (0.55 to 0.82 mm) than in *M. curema* (0.49 to 0.71 mm). Temporal segregation of the spawning season between *M. curema* and *M. liza* may avoid interspecific competition between offspring that recruit in inner bay areas. Additionally, greater fecundity and oocyte size in *M. liza* increase the chance of reproductive success during the dry season when there is less food resources for early juveniles.

KEY WORDS: fecundity, fish reproduction, interspecific competition, syntopic species, spawning.

Introduction	52
Material and methods	53
Results	54
Macroscopic morphology of gonads	54
Spawning season	55

² Corresponding author: Francisco G. Araújo, Universidade Federal Rural do Rio de Janeiro, Laboratório de Ecologia de Peixes, km 47, Antiga Rodovia Rio-São Paulo, 23851-970 Seropédica, RJ, Brazil (E-mail address: gerson@ufrj.br).

Fecundity	56
Discussion.....	58
Acknowledgements	59
References	60

INTRODUCTION

Natural selection leads to maximization of the lifetime production of offspring, and more importantly, to maximization of the survivorship of offspring until adulthood. The main objective of a reproductive strategy is to maximize reproductively active offspring in relation to available energy and parental life expectancy (ROFF 1992, PIANKA 2000). Fishes follow different strategies and tactics to achieve this (POTTS & WOOTTON 1984). Presumably both the overall strategy and the tactical variations are adaptive (STEARNS 1992). Closely related species should develop strategies to avoid interspecific competition for limited resources and to overcome environmental constraints (WOOTTON 1992, AMARASEKARE 2003). For example, timing segregation in reproduction will enable offspring to maximize the use of the available resources, enhancing survival and reproductive success.

Mugilids are widely distributed in coastal and brackish waters of all tropical and temperate regions of the world. In many countries, mugilids are targeted by commercial fisheries (IBÁÑEZ-IBAÑEZ-AGUIRRE & GALLARDO-CABELLO 2004) and have also been widely cultured (SIVALINGAM 1975, LEE & OSTROWSKI 2001). They are also one of the most important forage fishes found in estuaries and represent a significant food source for upper-level piscivores (McDONOUGH & WENNER 2003). Consequently, the reproductive biology of a number of mugilids has been well studied.

Fishes of the family Mugilidae are iteroparous (BRUSLE 1981, FENDER DE ANDRADE-TALMELLI et al. 1994) and highly fecund (GREELEY et al. 1987, OKUMUŞ & BAŞÇINAR 1997). Mulletts produce small pelagic eggs that typically develop in a group-synchronous pattern and they have two distinct size classes of oocytes present in mature ovaries. Mulletts release the larger class of oocytes in one to a few spawning events (CHAN & CHUA 1980, RENDER et al. 1995, KENDALL & GRAY 2008) taking place in the lower reaches of estuaries and in near-shore coastal waters.

Mugil liza Valenciennes 1836 and *Mugil curema* Valenciennes 1836 are the most abundant species of Mugilidae in southeastern Brazil and are very important as a fishery resource. In Sepetiba Bay, Rio de Janeiro State, *M. liza* and *M. curema* accounted for 99.7% of the total number of mulletts caught in experimental samplings between 1994 and 1997 (SILVA & ARAÚJO 2000). These species have similar feeding habits and offshore reproduction, and they use the inner bay areas to recruit (SILVA & ARAÚJO 2000, FROESE & PAULY 2008). Nevertheless, due to intraspecific and interspecific variation in spawning behavior (e.g., timing and duration), there is considerable variation in life-history characteristics of mugilids that inhabit similar environments (BRUSLE 1981). We hypothesize that

there are differences in reproductive traits, such as reproductive timing, in order to avoid offspring competition. To test this hypothesis, we compared the gonadal cycle, fecundity and oocyte diameter between these two species.

MATERIAL AND METHODS

Study area

SePETiba Bay is a sedimentary embayment in the southeastern region of Rio de Janeiro State (22°54'-23°04'S; 43°34'-44°10'W) with an area of ca 450 km² and open to the Atlantic Ocean on its western boundary. The bay has a mean depth of 8.6 m, a maximum depth of 30 m, and its drainage area is ca 2700 km² (ARAÚJO et al. 2002). The waters are predominantly polyhaline (salinity average = 30) and the mean temperature ranges from 21.5 °C in winter to 27 °C in summer (ARAÚJO et al. 2002). The annual rainfall is 1000-2100 mm (BARBIÉRI & KRONENBERG 1994) but does not cause great changes in the salinity of the bay because the streams and channels that drain into the bay are small. The rainfall period in the bay region is mainly between October and February (summer), though it can sometimes extend into March (BARBIÉRI & KRONENBERG 1994). The dry period extends from May to September (winter). Rainfall data were collected from Sepetiba Meteorological Base [(GEORIO FOUNDATION 2008), available at www.rio.rj.gov.br/georio].

Most of the bay has a substrate of silt and mud and a tidal range of approximately 1 m. Southwestern winds help move seawater into the bay and northeastern winds help take bay water out toward the continental shelf (SIGNORINI 1980). In the last few decades, the bay has undergone increasing degradation due to industrial outflows and municipal effluents brought into the bay by rivers and drainage channels on the outskirts of Rio de Janeiro city (PFEIFFER et al. 1985).

Data collection and analysis

We collected specimens from artisanal and commercial catches from July 2006 to June 2007 in the inner zone of Sepetiba Bay. The nets were 1500 m long, 3 m high and had three panels of different mesh sizes (35, 40 and 45 mm or 45, 50 and 55 mm stretched mesh sizes). This large mesh, designed to catch the larger fishes, mainly selects females, since females outnumber males in all size classes, with significant differences in the sex ratio for sizes larger than 500 mm LT for *M. liza* (ÁLBIERI & ARAÚJO 2010). Male mullets generally outnumber females of shorter lengths, while females outnumber males of greater lengths; this pattern has been reported for mullets elsewhere (NJOKU & EZEIBEKWE 1996, OKUMUŞ & BAŞÇINAR 1997, McDONOUGH et al. 2003).

We collected approximately 40 specimens of *M. liza* and of *M. curema* each month. Of these, 156 *M. liza* and 136 *M. curema* were examined to assess their reproductive biology. We measured total length (TL) to the nearest mm. Total (TW) and eviscerated (EW) weight were measured to the nearest gram, and gonad weight (GW) to 0.01 g. The gonadal macroscopic description followed ANDRADE-TALMELLI et al. (1996) and MARIN et al. (2003). Ripe ovaries were kept in Gilson solution to estimate fecundity and oocyte diameter.

The gonadosomatic index ($GSI = GW \times 100 \times EW^{-1}$) and frequency of gonad maturation stages were used to assess the gonadal cycle (VAZZOLER 1996). Eviscerated

weight was used in all index calculations to avoid the influence of the contents of the gonad and stomach on the weights. One-way analysis of variance (ANOVA) was used to compare GSI means among months ($P < 0.05$) and r-Spearman rank coefficient was used to assess the correlation between monthly rainfall and GSI. All data are expressed as means \pm standard error.

Absolute fecundity (F) was estimated by the gravimetric method as described by VAZZOLER (1996). Relative fecundity (RF) was calculated as F per gram of eviscerated body mass (KENDALL & GRAY 2008). The diameter of 300 mature oocytes chosen from each ripe ovary was measured with an ocular micrometer to 0.01 mm. Fecundity and oocyte diameter were compared between the two species with Student's *t*-test.

RESULTS

Macroscopic morphology of gonads

Ovaries are paired, elongated, covered by a thin peritoneal layer and range from filiform to piriform depending on the developmental stage. Cranial regions are larger and the ovaries get thinner toward the caudal portion. Each gonad duct lies on the dorsal-medial region. These ducts have a small joint leading to a common orifice. Throughout the gonads, the arteries occupy a supra-visceral position

Table 1.
Macroscopic description of *M. liza* and *M. curema* ovaries (modified from ANDRADE-TALMELLI et al. 1996 and MARIN et al. 2003).

Stages	Characteristics
Immature	Ovaries small, filiform and adhered to the swim-bladder. They are translucent with no sign of blood irrigation.
Developing	Ovaries are fusiform and wider than at the previous stage, occupying almost 1/3 the abdominal cavity, and reddish in color. There is some sign of blood irrigation.
Maturing	Ovaries wider and almost piriform, filling approximately 2/3 of abdominal cavity. They are reddish-yellow with a granular appearance due to the oocytes and the arteries are easily visible.
Ripe/Running ripe	Ovaries are large, piriform, yellow, smooth in appearance, turgid and round and occupy almost the entire abdominal cavity. Oocytes are easily distinguished macroscopically (as granular) and blood irrigation is evident.
Spent	Ovaries are flaccid and wrinkled, occupying about 1/2 of abdominal cavity. Purple in color.
Recovering/ Resting	The wall is thicker and rigid, and ovaries are fusiform, occupying less than 1/3 of the abdominal cavity. Cream in color and the ovarian mass is firm and reddish in color.

and spread through lateral ramifications that become evident during gonadal development. The right gonad is usually larger than the left. The maturation stages of ovaries are described in Table 1.

Spawning season

Mugil liza. The mean GSI showed seasonal differences during the study period ($F = 4.34$; $P < 0.01$; Fig. 1). The lowest GSI were recorded between October and March; these values then increased in April and May, peaked in June and then dropped sharply in July, August and September. There was a highly significant negative correlation ($P < 0.01$) between GSI and rainfall ($r = -0.76$). Ripe/running ripe ovaries were observed between May and August. Spent ovaries were recorded from May to September. Immature ovaries were observed between July and February; developing and recovering/resting ovaries were found throughout the study period. Maturing ovaries were observed from April to September (Fig. 2).

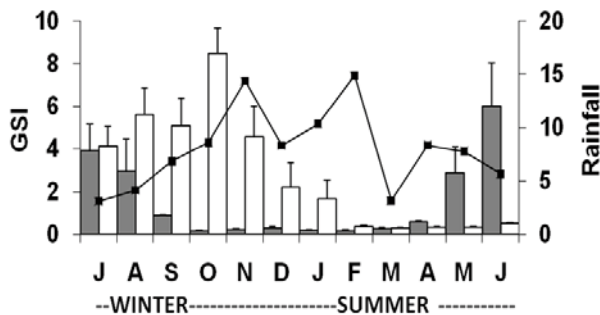


Fig. 1. — Monthly variation in rainfall (cm: ■-) and gonadosomatic index (GSI) of female *M. liza* (■) and *M. curema* (□).

Mugil curema. The mean GSI showed seasonal differences during the study period ($F = 8.56$; $P < 0.01$; Fig. 1). The lowest GSI were recorded between February and June; these values then increased in July and August, peaked in October and dropped sharply in November, December and January. No significant correlation ($P > 0.05$) was found between GSI and rainfall ($r = 0.04$). Ripe/running ripe ovaries were observed between August and January.

The only spent ovary was recorded in November. Immature and recovering/resting ovaries were recorded from December to January and from November to June, respectively. Developing ovaries were found throughout the study period, with the highest percentages in April and May. Maturing ovaries were observed between July and January, with the highest percentages in September and October (Fig. 2).

Fecundity

Mugil liza mature after reaching about 55 mm TL, whereas *M. curema* mature by 25 mm TL (Table 2). The absolute fecundity for 20 *Mugil liza* adults ranged from 241×10^4 to 365×10^4 oocytes (mean: $308 \times 10^4 \pm 104 \times 10^3$ oocytes) for females measuring 590 to 680 mm TL. Relative fecundity ranged from 871.72 to 1940.42 oocytes g^{-1} (mean: 1396.42 ± 67.02 oocytes g^{-1}) and the diameter of

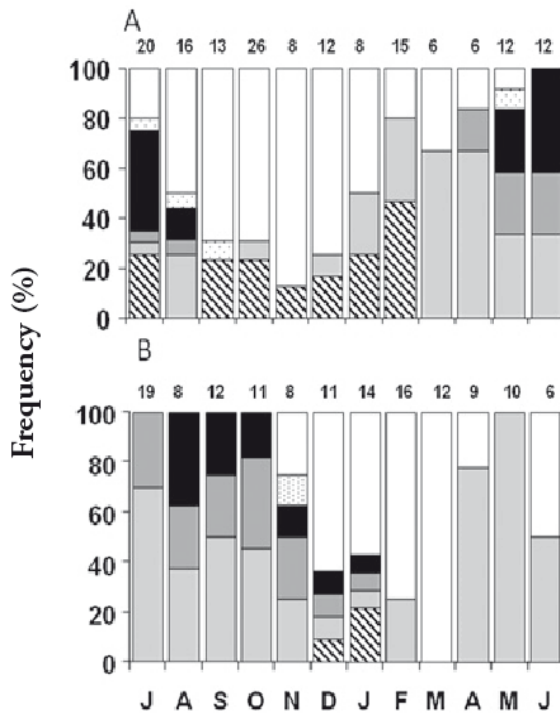


Fig. 2. — Monthly changes in the percentage of maturity stages of female *M. liza* (A) and *M. curema* (B). Sample sizes are given above bars. Recovering (□); Spent (▨); Ripe/running ripe (■); Maturing (▩); Developing (▧); Immature (▩).

Table 2.

Size class distribution (TL in mm), total weight (g) and reproductive endpoints of *M. liza* and *M. curema* females.

Species	Size class	<i>n</i>	Total weight	GSI	<i>n_f</i>	Absolute fecundity	Oocyte diameter
<i>Mugil liza</i>	30-35	1	365	0.02	0	—	—
	35-40	7	550.71 ± 28.83	0.15 ± 0.03	0	—	—
	40-45	38	845.02 ± 14.33	0.13 ± 0.02	0	—	—
	45-50	64	1050.84 ± 13.02	0.28 ± 0.03	0	—	—
	50-55	13	1382.30 ± 47.11	1.66 ± 1.39	0	—	—
	55-60	13	2051.53 ± 89.54	4.91 ± 1.78	5	293 × 10 ⁴ ± 22 × 10 ⁴	0.55-0.80
	60-65	14	2670 ± 86.28	8.33 ± 1.62	12	328 × 10 ⁴ ± 11 × 10 ⁴	0.60-0.82
	65-70	3	3105 ± 125	10.45 ± 0.88	3	342 × 10 ⁴ ± 12 × 10 ⁴	0.60-0.81
<i>Mugil curema</i>	20-25	7	165.71 ± 7.97	3.08 ± 1.92	1	124 × 10 ³	0.49-0.68
	25-30	52	242.53 ± 4.99	0.80 ± 0.28	1	151 × 10 ³	0.49-0.70
	30-35	27	366.88 ± 12.44	1.71 ± 0.48	2	242 × 10 ³ ± 54 × 10 ³	0.51-0.70
	35-40	43	627.74 ± 12.71	5.51 ± 0.68	16	454 × 10 ³ ± 31 × 10 ³	0.50-0.71
	40-45	7	773.52 ± 41.74	5.01 ± 1.07	2	562 × 10 ³ ± 59 × 10 ³	0.51-0.70

(*n* = sample size; GSI = gonadosomatic index; *n_f* = number of ovaries used to assess absolute fecundity and oocyte diameter, in mm; mean ± SE).

mature oocytes measured 0.55 to 0.82 mm. The absolute fecundity of 22 *Mugil curema* adults ranged from 123 × 10³ to 711 × 10³ oocytes (mean: 415 × 10³ ± 32 × 10³ oocytes) for females measuring 245 to 445 mm TL. Relative fecundity ranged from 497.46 to 1255.46 oocytes g⁻¹ (mean: 750.54 ± 40.52 oocytes g⁻¹) and the diameter of mature oocytes measured 0.49 to 0.71 mm. Both F and RF differed significantly (*P* = 0.00, *t* = 25.21 for F; *P* = 0.00, *t* = - 8.42 for RF) between the two species, with *M. liza* having higher values than *M. curema*. Oocyte diameter did not differ significantly (*P* > 0.05) between the two species. Absolute fecundity increased with body size and GSI while oocyte diameter did not change according to fish size, fecundity or GSI (Table 2).

DISCUSSION

Temporal segregation of the spawning seasons was found for *M. liza* and *M. curema*, with the former showing a shorter reproductive period of 4 months (May to August, peaking in July) and the latter a longer reproductive period of 6 months (August to January, peaking between August and October). SILVA & ARAÚJO (2000) reported peaks in recruitment of *M. liza* young-of-the-year in August. ARAÚJO et al. (1997) also found large numbers of *M. liza* juveniles in the inner bay zones during winter. These results match our findings, which indicate that the spawning of this species occurs in winter. Although no confirmatory information on the reproductive period of *M. curema* is available, our observations of GSI and frequency of gonadal stages indicate a reproductive period different from that of *M. liza*.

Different species may be limited by the same resource availability but differ in terms of when they exploit the resource (ARMSTRONG & MCGEEHEE 1980, CHESSON 2000). Segregation of the reproductive periods is attributed to the reduction of competition between offspring for space and available food resources. According to several authors (e.g. YÁÑEZ-ARACIBIA 1976, BLABER 2000, SILVA & ARAÚJO 2000, FROESE & PAULY 2008), mugilids have similar feeding habits, diets and recruitment habitats. Therefore, offspring competitive pressure could lead to the selection of different spawning periods of these two closely related species, a tactic used to enable coexistence since they use the same area to recruit.

Temporal separation of the spawning periods of mugilids has been reported elsewhere. COLLINS & STENDER (1989) collected mullet larvae of both species (*M. cephalus* Linnaeus 1758 and *M. curema*) in only 7.4% of neuston samples from February-May. IBÁÑEZ-AGUIRRE (1993) found that *M. cephalus* and *M. curema* coexist in Tamiahua Lagoon, with no difference in diet or digestive system but with a separation of 3 months in reproductive timing. DITTY & SHAW (1996) obtained *M. cephalus* larvae from the northern Gulf of Mexico between October and March, with peak abundance in November and December, and *M. curema* larvae between April and September, with peak abundance in April and May and a decrease from August to September. Differences in the reproductive period between congeneric and co-occurring mullets was also reported by IBÁÑEZ-AGUIRRE & GALLARDO-CABELLO (2004) for *M. cephalus* and *M. curema* in Venezuelan waters, and by KENDALL & GRAY (2008) for *Liza argentea* (Quoy & Gaimard 1825) and *Myxus elongatus* Günther 1861 in south-eastern Australia.

The periodicity of mullet reproduction may also be related to environmental variability in the signals for optimal early growth and survival. In the tropics, Mugilidae spawning encompasses the wet season (BLABER 2000). The spawning period of *M. curema* in Sepetiba Bay began just before the rainy season, suggesting that early juveniles could take advantage of the benefits of rainfall, such as food availability. MACGREGOR & HOUDE (1996) found that heavy rainfall seasons seem to increase plankton availability due to great amounts of nutrients carried by rivers, favoring the development of planktophagous fish. Early juvenile mullets (< 60 mm TL) are planktophagous (YÁÑEZ-ARACIBIA 1976, BLABER 2000); hence, the adults could spawn before the rainfall season in order to increase larval and

juvenile survival, since suitable food in bays, coastal lagoons, river deltas and estuarine mangrove areas has been identified as an important factor influencing the reproduction and recruitment of juvenile Mugilidae (YAÑEZ-ARACIBIA 1976, BLABER & BLABER 1980).

On the other hand, *M. liza* spawn during the dry season in winter when the water column and environmental conditions are stable in Sepetiba Bay (ARAÚJO et al. 2002). Although the food availability is higher during the rainy season, *M. liza* may use two tactics to overcome this environmental constraint. First, *M. liza* increases fecundity (mean F: $3,080,000 \pm 104 \times 10^3$ oocytes, mean RF = 1396.42 ± 62.02 oocytes g^{-1} for *M. liza*; mean F: $415,000 \pm 32 \times 10^3$ oocytes, mean RF 750.54 ± 40.52 oocytes g^{-1} for *M. curema*) and has slightly larger oocytes (diameter: 0.55 to 0.88 mm for *M. liza*; 0.49 to 0.71 mm for *M. curema*). Oocyte diameter did not change with fish size, fecundity or GSI. Our finding that oocyte diameter is unrelated to fish size contrasted with the reports by GALL (1974) and KAZAKOV (1981) of a significant positive correlation between size and oocyte diameter for salmonid species. However, WARE (1975) and BENGTON et al. (1987) pointed out that oocyte size is remarkably constant for a given marine fish species in a given geographical area.

Fecundity may vary due to different adaptations to environmental habitats (WITTHAMES et al. 1995) and is related to the feeding conditions in which the newly hatched larvae find themselves. Large larvae (large eggs) will be at an advantage when the plankton is sparse (WOOTTON 1992) but exceptions occur because some larger eggs have a larger perivitelline space and less nutritive yolk. Although *M. curema* has a longer reproductive period and better conditions for recruitment, *M. liza* developed high fecundity and slightly larger oocytes with a larger amount of yolk, enabling the larvae to survive and recruit even in a less favorable environment. Furthermore, the differentiation of spawning timing avoids competition between earlier juvenile recruitment, as mentioned before.

Mugil curema is a widespread mullet which coexists with *M. cephalus* mainly in the Gulf of Mexico (IBÁÑEZ-AGUIRRE & GALLARDO-CABELLO 2004), with *M. liza* in northeastern and southeastern Brazil (SILVA & ARAÚJO 2000), and with *Mugil platanus* Günther 1880 in southern Brazil (VIEIRA 1991). All those species (*M. cephalus*, *M. liza* and *M. platanus*) spawn in winter and have higher fecundity, larger eggs and reach larger sizes than *M. curema* which spawns mainly in spring. Therefore, it is reasonable to suppose that those three species developed a similar strategy to coexist with *M. curema*; the latter seems to use more favorable conditions to spawn whereas the former three species developed an alternative strategy to coexist.

ACKNOWLEDGEMENTS

Our thanks go to Iracema David Gomes for helping in laboratory tasks. Paulo Cesar da Silva and Adeilton do Nascimento helped in fieldwork. This research was partially funded by CAPES — Brazilian Agency for Higher Studies and Personal Graduation.

REFERENCES

- ALBIERI R.J. & ARAÚJO F.G. 2010. Reproductive biology of the mullet *Mugil liza* (Teleostei: Mugilidae) in a tropical Brazilian bay. *Zoologia* 27: 331-340.
- AMARASEKARE P. 2003. Competitive coexistence in spatially structured environments: a synthesis. *Ecological Letters* 6: 1109-1122.
- ANDRADE-TALMELLI E.Ĥ., ROMAGOSA E., NARAHARA M.Y. & GODINHO H.M. 1996. Reproductive characteristics of the mullet *Mugil platanus* (Teleostei, Peciformes, Mugilidae) in the Cananea estuarine-lagoon system, São Paulo. *Revista Ceres* 43: 165-185.
- ARAÚJO F.G., AZEVEDO M.C.C., SILVA M.A., PESSANHA A.L.M., GOMES I.D. & CRUZ-FILHO A.G. 2002. Environmental influences on the demersal fish assemblages in the Sepetiba Bay, Brazil. *Estuaries* 15: 441-450.
- ARAÚJO F.G., CRUZ-FILHO A.G., AZEVEDO M.C.C., SANTOS A.C.A. & FERNANDES L.A.M. 1997. Community structure of juvenile fishes in the continental margins of the Sepetiba bay, RJ. *Acta Biologica Leopoldinense* 19: 61-83.
- ARMSTRONG R.A. & MCGEHEE R. 1980. Competitive exclusion. *The American Naturalist* 115: 151-170.
- BARBIÉRI E.B. & KRONENBERG D.M. 1994. Climatology of the southeastern-southern coast of Rio de Janeiro State. *IBGE, Caderno de Geociências* 12: 57-73.
- BENGTSON D.A., BARKMAN R.C. & BERRY W.J. 1987. Relationships between maternal size, egg diameter, time of spawning season, temperature, and length at hatch of Atlantic silverside, *Menidia menidia*. *Journal of Fish Biology* 31: 697-704.
- BLABER S.J.M. (Edit.) 2000. *Tropical estuarine fishes: Ecology, exploitation and conservation*. Oxford: Blackwell Science, XII + 384 pp.
- BLABER S.J.M. & BLABER T.G. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *Journal of Fish Biology* 17: 143-162.
- BRUSLE J. 1981. Sexuality and biology of reproduction of grey mullets, pp. 99-154. In: Oren O.H., Edit. *Aquaculture of Grey Mullet*. International Biological Programme. New York: Cambridge University Press, 507 pp.
- CHAN E.H. & CHUA T.E. 1980. Reproduction in the greenback grey mullet, *Liza subviridis* (Valenciennes, 1836). *Journal of Fish Biology* 16: 505-519.
- CHESSON P. 2000. General theory of competitive coexistence in spatially-varying environments. *Theoretical Population Biology* 58: 211-237.
- COLLINS M.R. & STENDER B.W. 1989. Larval striped mullet (*Mugil cephalus*) and white mullet (*Mugil curema*) off the southeastern United States. *Bulletin of Marine Science* 45: 580-589.
- DITTY J.G. & SHAW R.F. 1996. Spatial and temporal distribution of larval striped mullet (*Mugil cephalus*) and white mullet (*Mugil curema*, family: Mugilidae) in the northern Gulf of Mexico, with notes on mountain mullet, *Agonostomus monticola*. *Bulletin of Marine Science* 59: 271-288.
- FENDER DE ANDRADE-TALMELLI E., ROMAGOSA E., NARAHARA M.Y. & GODINHO H.M. 1994. The occurrence of hermaphroditism in the mullet *Mugil platanus* (Pisces, Mugilidae) at Cananea estuarine region, Sao Paulo State, Brazil. *Boletim do Instituto de Pesca* 21: 111-116.
- FROESE R. & PAULY D. (Edits) 2008. FishBase. *World Wide Web electronic publication* (<http://www.fishbase.org>. Version 07/2008).
- GALL G.A.E. 1974. Influence of size of eggs and age of female on hatchability and growth in rainbow trout. *California Fish and Game* 60: 26-36.
- GEORIO FOUNDATION 2008. Municipality of Rio de Janeiro, Secretaria Municipal de Obras. *World Wide Web electronic publication* (<http://www.rio.rj.gov.br/georio> Version 07/2008).

- GREELEY M.S., CALDER D.R. & WALLACE R.A. 1987. Oocyte growth and development in the striped mullet, *Mugil cephalus*, during seasonal ovarian recrudescence: relationship to fecundity and size at maturity. *Fishery Bulletin* 85: 187-200.
- IBÁÑEZ-AGUIRRE A.L. 1993. Coexistence of *Mugil cephalus* and *M. curema* in a coastal lagoon in the Gulf of Mexico. *Journal of Fish Biology* 42: 959-961.
- IBÁÑEZ-AGUIRRE A.L. & GALLARDO-CABELLO M. 2004. Reproduction of *Mugil cephalus* and *Mugil curema* (Pisces: Mugilidae) from a coastal lagoon in the Gulf of Mexico. *Bulletin Marine Science* 75: 37-49.
- KAZAKOV R.V. 1981. The effect of the size of Atlantic salmon, *Salmo salar* L., eggs on embryos and alevins. *Journal of Fish Biology* 19: 353-360.
- KENDALL W.B. & GRAY C.A. 2008. Reproductive biology of two co-occurring mugilids, *Liza argentea* and *Myxus elongatus*, in south-eastern Australia. *Journal of Fish Biology* 73: 963-979.
- LEE C.S. & OSTROWSKI A.C. 2001. Current status of marine finfish larviculture in the United States. *Aquaculture* 200: 89-109.
- MACGREGOR J.M. & HOUDE E.D. 1996. Onshore-offshore pattern and variability in distribution and abundance of bay anchovy *Anchoa mitchilli* eggs and larvae in Chesapeake Bay. *Marine Ecology Progress Series* 138: 15-25.
- MARIN E.B.J., QUINTERO A., BUSSIÈRE D. & DODSON J.J. 2003. Reproduction and recruitment of white mullet (*Mugil curema*) to a tropical lagoon (Margarita Island, Venezuela) as revealed by otolith microstructure. *Fishery Bulletin* 101: 809-821.
- MCDONOUGH C.J., ROUMILLAT W.A. & WENNER C.A. 2003. Fecundity and spawning season of striped mullet (*Mugil cephalus* L.) in South Carolina estuaries. *Fishery Bulletin* 101: 822-834.
- MCDONOUGH C.J. & WENNER C.A. 2003. Growth, recruitment, and abundance of juvenile *Mugil cephalus* in South Carolina estuaries. *Fishery Bulletin* 101: 343-357.
- NJOKU D.C. & EZEIBEKWE I.O. 1996. Age composition and growth of the large-scaled mullet, *Liza grandisquamis* (Pisces: Mugilidae), Valenciennes, 1836 on the New Calabar estuary, off the Nigerian coast. *Fisheries Research* 26: 67-73.
- OKUMUŞ I. & BAŞÇINAR N. 1997. Population structure, growth and reproduction of introduced Pacific mullet, *Mugil soiyu*, in the Black Sea. *Fishery Research* 33: 131-137.
- PFEIFFER W.C., LACERDA L.D., FIZSMAN M. & LIMA N.R.W. 1985. Heavy metal in fishes from Sepetiba Bay, Rio de Janeiro State. *Ciência and Cultura* 37: 297-302.
- PIANKA E.R. (Edit.) 2000. Evolutionary ecology, 6th ed. San Francisco: Benjamin-Cummings, Addison-Wesley-Longman, 512 pp.
- POTTS G.W. & WOOTTON R.J. (Édits) 1984. Fish reproduction: Strategies and tactics. London: Academic Press, 424 pp.
- RENDER J.H., THOMPSON B.A. & ALLEN R.L. 1995. Reproductive development of striped mullet in Louisiana estuarine waters with notes on the applicability of reproductive assessment methods for isochronal species. *Transactions of the American Fisheries Society* 124: 26-36.
- ROFF D.A. (Edit.) 1992. The evolution of life histories: Theory and analysis. New York: Chapman and Hall, XII + 535 pp.
- SIGNORINI S.R. 1980. A study of the circulation in bay of Ilha Grande and bay of Sepetiba, Part I. A survey of the circulation based on experimental field data. *Boletim do Instituto Oceanográfico* 29: 41-55.
- SILVA M.A. & ARAÚJO F.G. 2000. Distribution and abundance of mullets (Osteichthyes, Mugilidae) in the Sepetiba Bay, RJ, Brazil. *Revista Brasileira de Zoologia* 17: 473-480.

- SIVALINGAM S. 1975. On the grey mullets of the Nigerian coast, prospects of their culture and results of trials. *Aquaculture* 5: 345-357.
- STEARNS S.C. (Edit.) 1992. The evolution of life histories. *Oxford: Oxford University Press*, XII + 249 pp.
- VAZZOLER A.E.A.M. (Edit.) 1996. Biology of reproduction of teleosts: Theory and practice. *EDUEM: Maringá*, XVIII + 169 pp.
- VIEIRA J.P. 1991. Juvenile mullets (Pisces: Mugilidae) in the estuary of Lagoa dos Patos, RS, Brazil. *Copeia*: 409-418.
- WARE D.M. 1975. Relation between egg size, growth, and natural mortality of larval fish. *Journal of the Fisheries Research Board of Canada* 32: 2503-2512.
- WITTHAMES P.R., GREER-WALKER M., DINIS M.T. & WHITING C.L. 1995. The geographical variation in the potential annual fecundity of dover sole, *Solea solea*, from European shelf waters during 1991. *Netherlands Journal of Sea Research* 34: 45-58.
- WOOTTON R.J. (Edit.) 1992. Fish ecology. *London: Chapman and Hall*, X + 212 pp.
- YÁNEZ-ARACIBIA L.A. 1976. Observaciones sobre *Mugil curema* Valenciennes, em áreas naturais de criação, maturación, crescimento, madurez y relaciones ecológicas. *Anales del Centro de Ciencias del Mar y Limnología* 2: 211-243.