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Christopher R. Spruck
University of Georgia

Randal L. Walker
University of Georgia

Mary L. Sweeney
University of Georgia

Dorset H. Hurley
University of Georgia

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GAMETOGENIC CYCLE IN THE NON-NATIVE ATLANTIC SURF CLAM, *SPISULA SOLIDISSIMA* (DILLWYN, 1817), CULTURED IN THE COASTAL WATERS OF GEORGIA

Christopher R. Spruck[1], Randal L. Walker*, Mary L. Sweeney, and Dorset H. Hurley
Shellfish Research Laboratory, Marine Extension Service, University of Georgia, 20 Ocean Science Circle, Savannah, Georgia 31411-1011

ABSTRACT This study describes the gametogenic cycle of the Atlantic surf clam, *Spisula solidissima* (Dillwyn, 1817), cultured from fall to spring in the coastal waters of Georgia, where it is non-native. Early active stages of gametogenic development began in November, with the majority (83%) of the animals in the early active stage by December. Gonadal indices increased to late active stages by March, with ripe individuals present in April. Spawning commenced in May and continued into June. Sex ratio (0.48 female to 1.00 male) was significantly unequal. Results of this study indicate that clams achieved sexual maturity and spawned when cultured in the coastal waters of Georgia. An aquacultural enterprise in Georgia could obtain broodstock for the production of the following fall's seed crop from the prior year's growout field planted clams before their spring harvest.

Introduction

The Atlantic surf clam, *Spisula solidissima* (Dillwyn, 1817), occurs from Nova Scotia to North Carolina (Abbott 1974) and represents the second most valuable clam fishery in the United States. The potential for the development of aquaculture for yearling surf clams in the northeastern US has been investigated (Goldberg 1980, 1989) and attempted commercially (Monte, personal communications). In Georgia, juvenile Atlantic surf clams planted in fall and harvested in spring exhibited some of the fastest growth rates recorded for this species. Clams planted in November (at approximately 10 mm in shell length) achieved a mean size of 50 mm in shell length by May (Goldberg and Walker 1990; Walker and Heffernan 1990a,b,c,d). The size of this animal is ideal for the raw or steamer clam markets (Krzynowek et al. 1980; Krzynowek and Wiggin 1982). Experimental growout trials in Georgia indicate that the potential for surf clam aquaculture in the southeastern U.S. is excellent (Goldberg and Walker 1990; Walker and Heffernan 1990a,b,c,d). Surf clams must be harvested by mid to late spring (April/May), since high summer water temperatures (>28°C) that occur in coastal Georgia would cause physiological stress resulting in 100% mortality (Goldberg 1989).

The Georgia Department of Natural Resources currently bans the importation of bivalve seed into the state due to the threat of possible importation of shellfish pathogens along with the seed stock. Therefore, an aquacultural industry would need another method of continuing the propagation and replenishment of stocks for the following year's crop. This study determines the gametogenic cycle of the non-native Atlantic surf clam when cultured under field conditions in the coastal waters of Georgia and investigates whether or not field-planted animals reach sexual maturity and spawn within a single year. If this occurs, then a major biological hurdle to the development of this clam as a commercial aquacultural species for the southeastern US fishermen will be overcome.

Materials and Methods

The first generation of surf clams was spawned within the Shellfish Research Laboratory in the spring of 1991 under guidelines established for the culturing of exotic species by the International Council for the Exploration of the Seas (ICES). The second generation, used in this experiment, was spawned in the laboratory on 5 May 1992. Juveniles were cultured in upwellers and fed *Skeletonema* sp. and *Isochrysis galbana* (Tahitian strain) within a temperature controlled room [23 ± 2.0 (SE) °C] from June until 10 October 1992. On 10 October 1992, clams [19.4 ± 0.12 (SE) mm shell length] were field-planted in 12 mm mesh vinyl coated wire cages (N = 9 cages) at a density of 200 clams per cage (1 m x 1 m x 0.25 m cage). Cages were buried approximately 0.1 m deep at the mean low water mark on a sand flat near the mouth of House Creek, Little Tybee Island, Georgia (Figure 1). In mid-March, cages and animals were transplanted to the spring low water mark. This was done to extend the length of the feeding period in the hopes of enhancing growth rate.

Between October 1992 and June 1993, 30 clams were randomly collected each month from a different cage, measured for shell length (i.e. longest possible measurement,

*Corresponding author

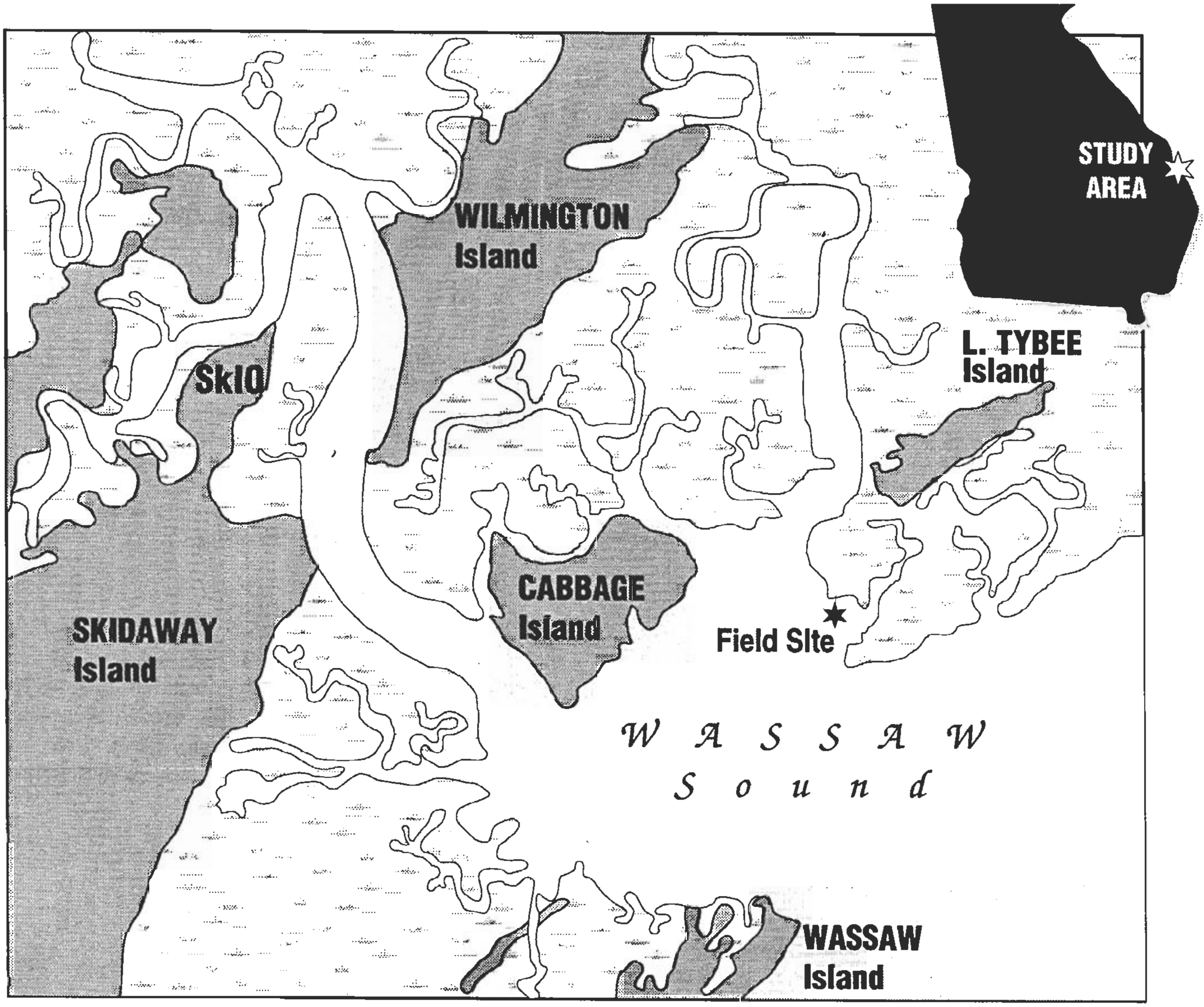

Figure 1. Location of field growout site of *Spisula solidissima* at the mouth of House Creek, Little Tybee Island, Georgia. SkIO (Skidaway Institute of Oceanography) denotes the site where daily temperatures were recorded.

anterior-posterior), and a mid-lateral gonadal sample (ca 1 cm^2) was dissected from each clam. Gonadal tissue was fixed in Davidson's solution, refrigerated for 48 hours, washed with 50% ethanol (Etoh), and held in 70% Etoh until processing. Tissue samples were processed according to procedures outlined in Howard and Smith (1983).

Prepared gonadal slides were examined with a Zeiss Axiovert 10 microscope (20X), sexed, and assigned to a developmental stage as described by Ropes (1968) and Kanti et al. (1993). Staging criteria of 0 to 5 were employed for Early Active (EA=3), Late Active (LA=4), Ripe (R=5), Partially Spawned (PS=2), Spent (S=1), and Inactive (IA=0). Monthly gonadal index (G.I.) values were determined for each sex by averaging the number of specimens ascribed to each category score.

Sex ratios were tested against a 1:1 ratio with Chi-Square statistics (Elliott 1977). Statistical analysis of mean gonadal index values was performed by Analysis of Variance (ANOVA) and Tukey's Studentized Range Tests (SRT) using SAS for PC software (SAS Institute 1989).

Water temperatures were recorded daily at 0800 from October 1992 to June 1993 at the dock of the Marine Extension Service, Skidaway Island, Georgia, and are presented as biweekly means in Figure 2. This site is approximately 4.5 nautical miles inland from the site where clams were field-planted. Temperature recorders

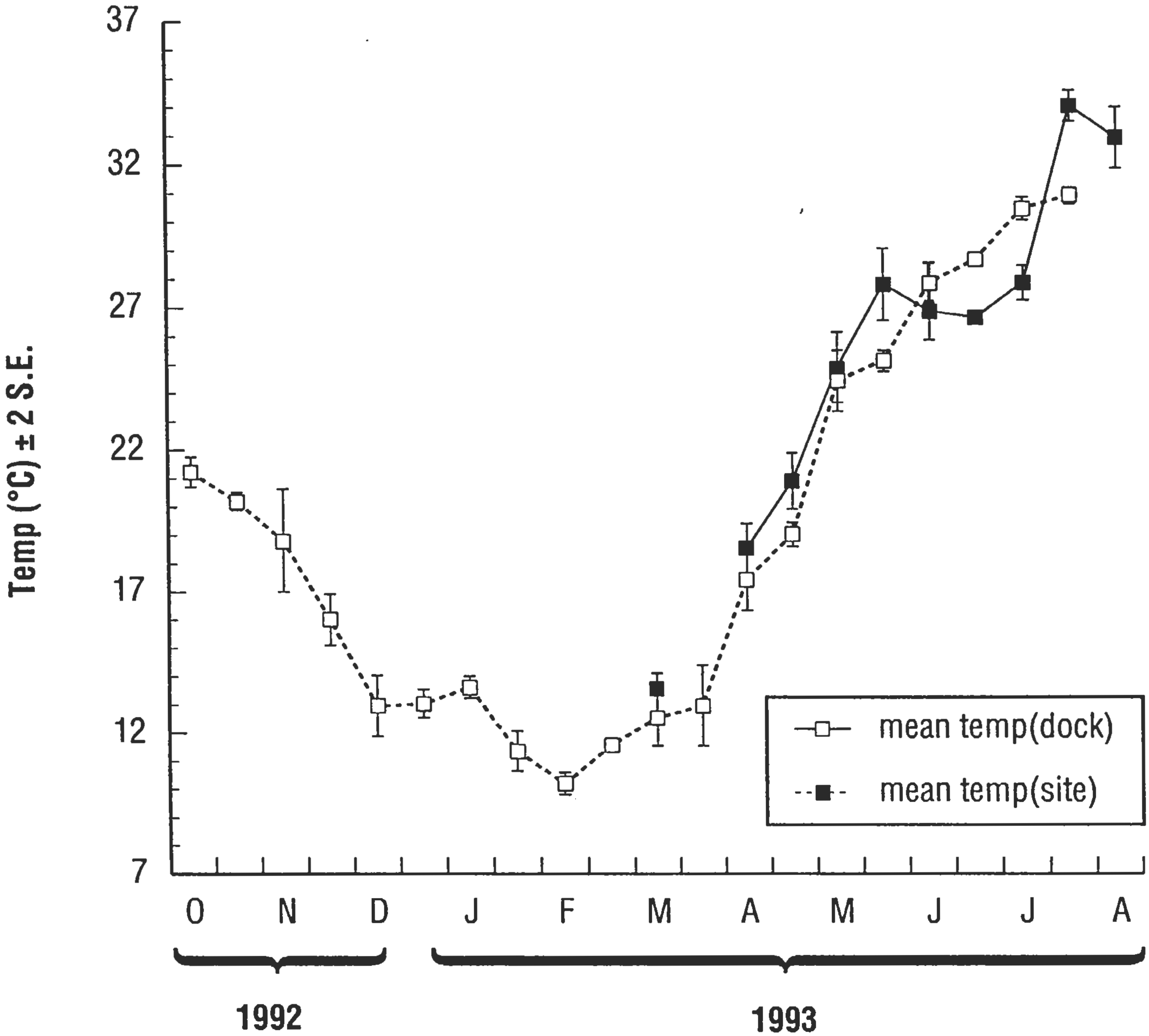

Figure 2. Mean ambient water temperatures taken at the Marine Extension Service Dock, Skidaway River from October 1992 to June 1993 and from the field grow out site from April to August 1993.

were placed on site from March to June 1993. As shown in Figure 2, water temperatures at the dock location are generally representative of temperatures at the test site.

Results

Surf clams grew from a mean shell length of 19.4 mm to 42.6 mm under field conditions from October 1992 to June 1993. Size increased steadily from November until March, remained the same between March ($\bar{x}$ = 36.2 mm) and April ($\bar{x}$ = 35.9) and increased again from April to June (Figure 3). The decrease in growth rate between March and April was probably caused by the stress endured by the animals when cages were moved to the spring low water mark from the mean low water mark.

Surf clams were inactive (96.6% of total) and early active (3.4% of total) in October 1992 (Figure 4), at a mean water temperature of 21.3°C (Figure 3). By December ($\bar{x}$ temperature = 13.0°C), 83% of the animals ($\bar{x}$ shell length = 25 mm) were in the early active stage. By March ($\bar{x}$ temperature = 12.5°C), 70% of the total surf clams

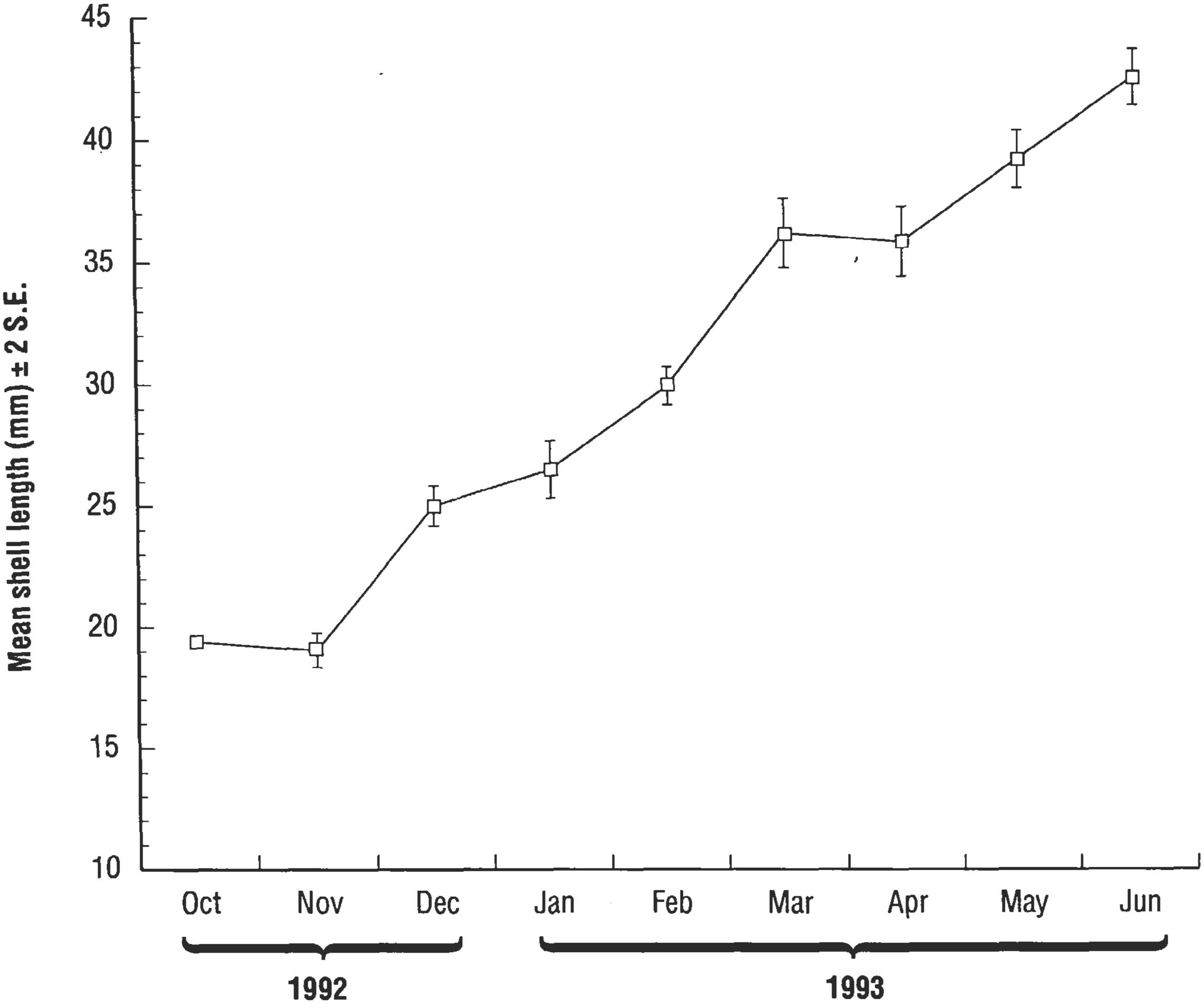

Figure 3. The increase in shell length of the non-native surf clams, *Spisula solidissima*, planted at the mean low water mark on an intertidal sandflat at the mouth of House Creek, Little Tybee Island, Georgia.

collected were in the late active stage. In early April ($\bar{x}$ temperature = 18.5°C), 55.6% of the total surf clams collected were in the late active stage and 44.4% were in the ripe stage. Water temperatures increased steadily and in early May reached a mean of 24.9°C when 17.2% of the surf clams were partially spent, 48.3% were late active, and 34.5% were ripe. By June ($\bar{x}$ temperature = 28.3°C, $\bar{x}$ shell length = 42.6 mm), 39.3% of the clams were spent and 60.7% were partially spent.

Mean gonadal indices for male and female clams are presented in Figure 5. Statistical analysis showed that there were no significant differences ($p = 0.8$) between male and female gonadal indices; therefore, mean values presented below are combined means of both sexes. Gonadal indices increased to late active stages by March ($\bar{x}$ G.I. = 4.0), with ripe individuals being encountered in April ($\bar{x}$ G.I. = 4.5). Spawning began in May ($\bar{x}$ G.I. = 4.0) and continued into June ($\bar{x}$ G.I. = 1.6) (Figure 4).

A total of 259 clams were histologically sectioned, of which 32.8% were undifferentiated, 45.6% were males, and 32.8% were females. The sex ratio was 0.48 female:1.00 male and significantly differed from parity ($\chi^2 = 22.09$; $P < 0.0001$).

DISCUSSION

Results of this study indicate that non-native Atlantic surf clams, reared within the coastal waters of Georgia, attained sexual maturity and spawned. In Georgia, spawning occurs in spring at approximately the time that field planted animals must be harvested. Once ambient water temperatures exceed 28°C, total mortality results. Spawning commenced in May after a 7°C increase in temperature from early April ($\bar{x}$ = 18.6°C) through May ($\bar{x}$ = 24.9°C). This pattern reflected that of a population off the shore of

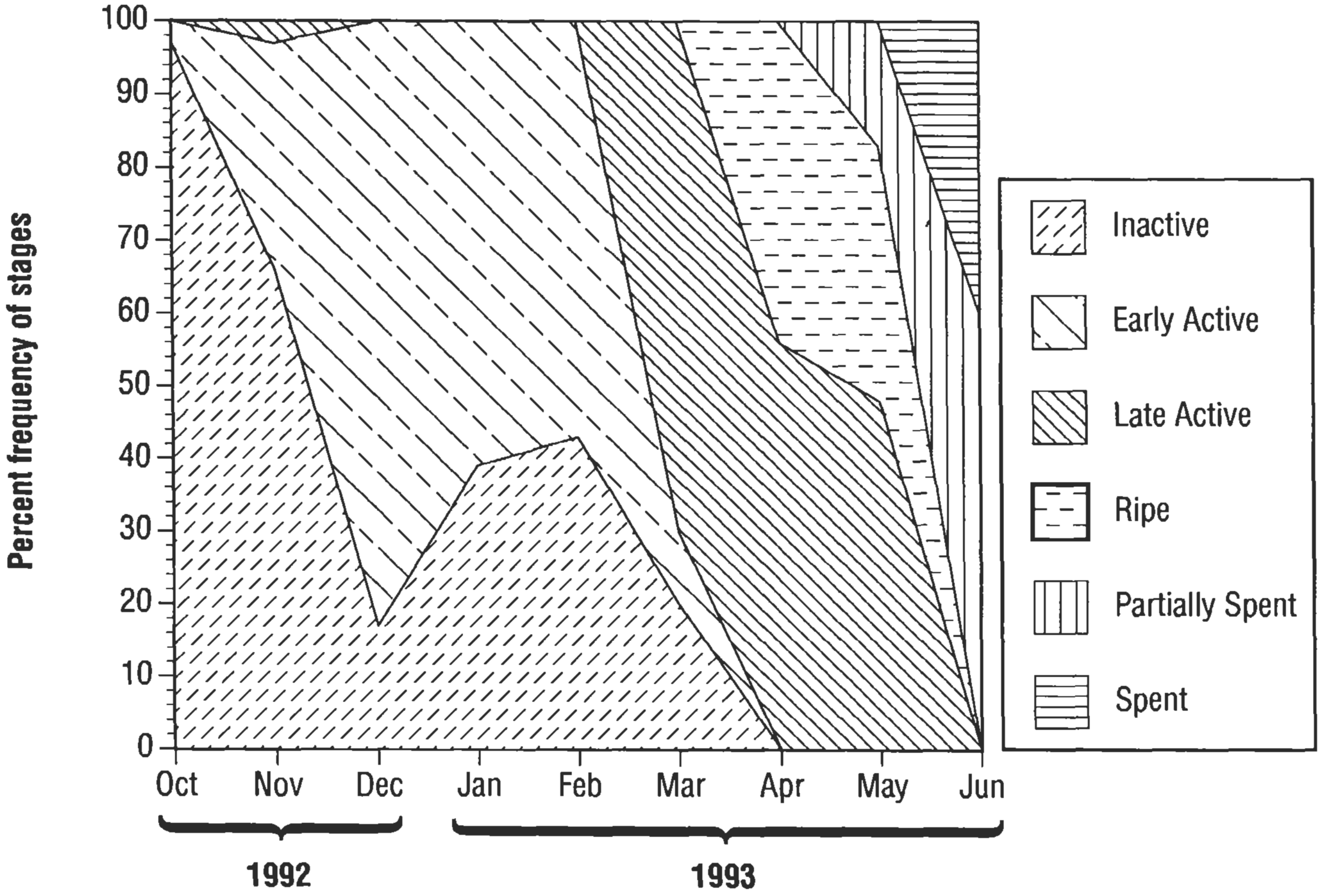

Figure 4. The percent frequency of surf clams, *Spisula solidissima*, in each developmental stage for animals cultured in cages at House Creek, Little Tybee Island, Georgia.

New Jersey as characterized by Ropes (1968). A clam farmer in Georgia could obtain broodstock from field growout plots prior to temperature-induced mortality and the final harvest of the crop. Broodstock could be supplied to a hatchery for either further conditioning in temperature-regulated tanks or animals could be spawned directly after collection. A hatchery operator could produce seed needed for the following fall field planting from yearling animals.

One consideration in using yearling surf clams for broodstock is the unequal sex ratio, since there are fewer females produced within the yearling age group. Unequal sex ratio is not an uncommon phenomenon among juvenile bivalves. In this study, yearling surf clams had a sex ratio of 0.48 female to 1.00 male. Equal sex ratios for surf clams in field populations have been reported (Ropes 1968; Jones 1981; Sephton 1987; Kanti et al. 1993). However, it is not unusual for protandrous bivalves to mature primarily as males within the first breeding season before equal sex ratios occur in older age classes (Joosse and Geraert 1983; Eversole 1989). This has been observed for *Mercenaria mercenaria* (Eversole et al. 1980; Dalton and Menzel 1983; Walker and Heffernan 1995), *Arctica islandica* (Rowell et al. 1990), and *Panope abrupta* (Goodwin 1976; Sloan and Robinson 1984) populations.

Since bivalve fecundity is related to size (Eversole 1989), older, larger females will produce more eggs per spawn. Thus, it would be prudent for the hatchery operator to keep yearling females within the hatchery under regulated water temperatures over summer and replant them in field plots the following fall.

In this study, the Atlantic surf clam achieved sexual maturity within approximately one year when cultured within the coastal waters of Georgia. Spawning occurred between May and June when animals were at a mean size of 39.2 mm and 42.6 mm, respectively. Although the clams were reared in non-native conditions, sexual maturity occurred at a smaller size than previously recorded for *Spisula*. Belding (1910) in Massachusetts found that sexual maturity could occur in yearling surf clams at a size of 39 mm, but that the majority of clams matured at two years of age and at a size of 67 mm in shell length. Ropes et al. (1969) observed that for an inshore population of clams in Chincoteaque Inlet, Virginia, yearling surf clams attained sexual maturity at a shell length of 45 mm. For a

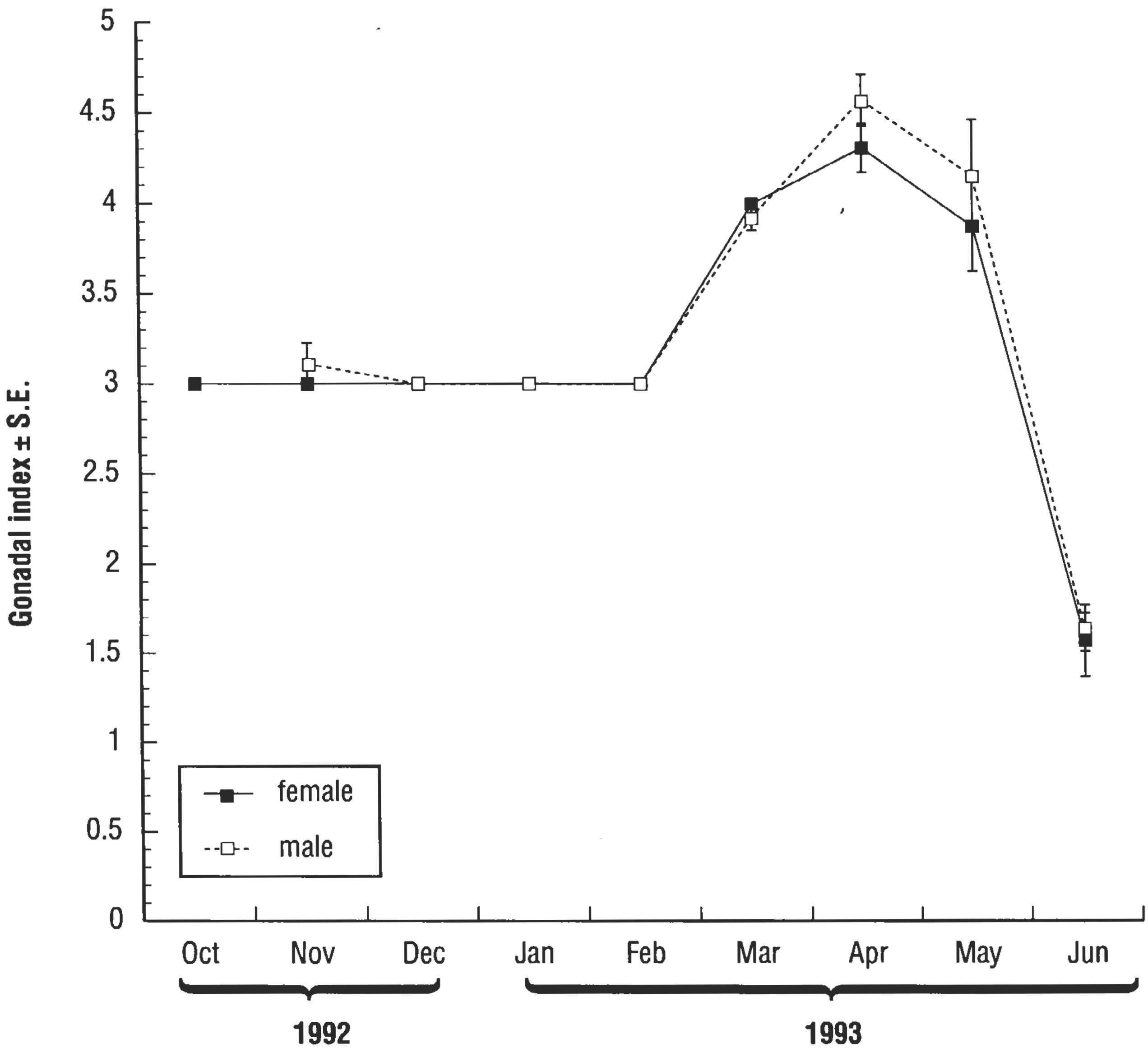

Figure 5. Mean gonadal indices for male and female surf clams, *Spisula solidissima*, cultured in cages at House Creek, Little Tybee Island, Georgia.

Canadian population, sexual maturity occurred at four years of age and at a size of 80 mm (Sephton and Bryan 1990).

In this study, Georgia hatchery-produced seed (19 mm) obtained a mean size of 42.6 mm by June when field planted in Georgia, whereas, in previous studies, a mean size of 60 mm in shell length had been achieved (Walker and Heffernan 1990a,b). The slower growth observed between March and April is probably related to the initial mean low water planting height and disruption caused by cage movement. Surf clams achieve greater size when planted at the spring low water mark and subtidal areas than at the mean low water mark (Walker and Heffernan 1990b). Thus, greater-sized individuals with a greater potential fecundity can be produced by planting the crop lower in the intertidal zone or in subtidal areas.

If a surf clam aquacultural industry develops in Georgia or the southeastern US, the need for the continual introduction of non-native seed from northern US areas or hatcheries would be eliminated. An aquacultural enterprise in Georgia could obtain broodstock for the production of the following fall's seed crop from the prior year's growout field planted clams before their spring harvest. Thus, once animals are brought into the state under the ICES guidelines for the introduction of exotic species, an industry can be developed from stocks supplied by that single introduction.

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LITERATURE CITED

Abbott, R.T. 1974. American Seashells, Second Edition. Van Nostrand Reinhold, NY. 663 p.

Belding, D.L. 1910. The growth and habits of the sea clam (*Mactra solidissima*). Rep Comm Fish Game Mass 1909 Publ Doc 25:26-41.

Dalton, R. and R.W. Menzel. 1983. Seasonal gonadal development of young laboratory-spawned southern (*Mercenaria campechiensis*) and northern (*Mercenaria mercenaria*) quahogs and their reciprocal hybrids in northern Florida. J Shellfish Res 2:11-17.

Elliott, J.M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biol Assoc Sci Pub 25, 160 pp.

Eversole, A.G. 1989. Gametogenesis and spawning in North American clam populations: Implications for culture. In: J.J. Manzi, and M.A. Castagna (eds.), Clam Mariculture in North America. Development in Aquaculture and Fisheries Science, Volume 19, p 75-110. Elsevier, NY.

Eversole, A.G., W.K. Michener, and P.J. Eldercidge. 1980. Reproductive cycle of *Mercenaria mercenaria* in a South Carolina estuary. Proc Natl Shellfish Assoc 70:20-30.

Goldberg, R. 1980. Biological and technological studies on the aquaculture of the yearling surf clams. Part I: Aquacultural production. Proc Natl Shellfish Assoc 70:55-60.

_____. 1989. Biology and culture of the surf clam. In: J.J. Manzi and M. Castagna (eds.), Clam Mariculture in North America. Development in Aquaculture and Fisheries Science, Volume 19, p 263-276. Elsevier, NY.

Goldberg, R. and R.L. Walker. 1990. Cage culture of yearling surf clams, *Spisula solidissima*, in coastal Georgia. J Shellfish Res 9:187-194.

Goodwin, C.L. 1976. Observations on the spawning and growth of subtidal geoducks (*Panope generosa* Gould). Proc Natl Shellfish Assoc 65:49-58.

Howard, D.W. and C.S. Smith. 1983. Histological techniques for marine bivalve mollusks. NOAA Technical Memorandum NMFS-F/NEC-25. 97 p.

Jones, D.S. 1981. Reproductive cycles of the Atlantic surf clam, *Spisula solidissima*, and the ocean quahog, *Artica islandica* off New Jersey. J Shellfish Res 1:23-32.

Joosse, J. and W.P.M. Geraert. 1983. Endocrinology. In: A.S.M. Saleuddin and K.M. Wilbur (eds.), The Mollusca, Volume 4, Physiology Part I, p 317-406. Academic Press, NY.

Kanti, A., P.B. Heffernan, and R.L. Walker. 1993. Gametogenic cycle of *Spisula solidissima similis* (Say, 1822) from St. Catherines Island, Georgia. J Shellfish Res 12:255-261.

Krzynowek, J., R.J. Learson, and K. Wiggin. 1980. Biological and technological studies on the aquaculture of yearling surf clams. Part II. Technological studies on utilization. Proc Natl Shellfish Assoc 70:61-64.

Krzynowek, J. and K. Wiggin. 1982. Commercial potential of cultured Atlantic surf clams *Spisula solidissima* (Dillwyn). J Shellfish Res 2:173-175.

Monte, D. 1986. Mercenaria Manufacturing Inc., Millsboro, Delaware (personal communication).

Ropes, J.W. 1968. Reproductive cycle of the surf clam, *Spisula solidissima*, in offshore New Jersey. Biol Bull 135:349-365.

Ropes, J.W., J.L. Chamberlin, and A.S. Merrill. 1969. Surf clam fishery. In: F.E. Firth (ed.), The Encyclopedia of Marine Resources. Van Nostrand, Reinhold Co., NY. 740 p.

Rowell, T.W., D.R. Chaisson, and J.T. McLane. 1990. Size and age of sexual maturity and annual gametogenic cycle in the ocean quahog, *Arctica islandica* (Linnaeus, 1767), from coastal waters in Nova Scotia, Canada. J Shellfish Res 9:195-203.

SAS Institute, Inc. 1989. SAS Language and Procedures: Usage. SAS Institute, Inc., Version 6, First Edition.

Sephton, T.W. 1987. The reproductive strategy of the Atlantic surf clam, *Spisula solidissima* (Dillwyn, 1817), in Prince Edward Island, Canada. J Shellfish Res 6:97-102.

Sephton, T.W. and C.F. Bryan. 1990. Age and growth determinations for the Atlantic surf clam, *Spisula solidissima* (Dillwyn, 1817), in Prince Edward Island, Canada. J Shellfish Res 4:177-186.

Sloan, N.A. and S.M.C. Robinson. 1984. Age and gonadal development in the geoduck, *Panope abrupta* (Conrad), from southern British Columbia, Canada. J Shellfish Res 4:131-137.

Walker, R.L. and P.B. Heffernan. 1990a. Plastic mesh covers for field growing of clams, *Mercenaria mercenaria* (L.), *Mya arenaria* (L.), and *Spisula solidissima* (Dillwyn), in the coastal waters of Georgia. Ga J Science 48:88-95.

_____. 1990b. The effects of cage mesh size and tidal level placement on the growth and survival of clams, *Mercenaria mercenaria* (L.), and Atlantic surf clams, *Spisula solidissima* (Dillwyn), in the coastal waters of Georgia. NE Gulf Sci 11:29-38.

_____. 1990c. Intertidal growth and survival of northern quahogs, *Mercenaria mercenaria* (Linnaeus, 1758) and Atlantic surf clams, *Spisula solidissima* (Dillwyn, 1817), in Georgia. J World Aquaculture Soc 21:307-313.

_____. 1990d. Mariculture potential of the Atlantic surf clam, *Spisula solidissima* (Dillwyn, 1817), in the coastal waters of Georgia. Ga J Sci 48:168-176.

_____. 1995. Sex ratio of northern quahog according to age, size, and habitat from coastal Georgia. Submitted to Trans Amer Fish Soc.