MOVEMENT AND BEHAVIOR OF WHELKS (FAMILY MELONGENIDAE) IN GEORGIA COASTAL WATERS

by

JACOB D. SHALACK

(Under the Direction of Randal L. Walker)

ABSTRACT

Two studies were performed: 1) to examine whelk harvest potential and the pot efficiency of five types of traps and 2) to examine the movement and behavior of the knobbed whelk, *Busycon carica* (Gmelin 1791) on intertidal flats. A total of 734 whelks [47.7% *Busycotypus canalicalatus* (Linnaeus, 1758), 34.7% *B. carica*, 17.6% *Busycotypus spiratus* (Hollister 1958)] were caught during the trapping study in Wassaw Sound and Beard Creek, Georgia. Traps with smooth plastic surfaces caught more whelks than traps without at both locations. During the tracking study at Wassaw Island, Georgia, initial whelk movement was a random spreading out from the release point. By day 8, whelks had concentrated on and near live oyster reefs. The average individual minimum daily movement rate was significantly shorter for males as compared to females (ANOVA $p<0.0001$). Whelks also shifted from surface to more buried positions as daytime temperatures increased (Chi squared $\alpha=0.05$).

INDEX WORDS: Whelk, Movement, Trapping, Fishery, Wassaw Sound, GIS, *Busycon*, *Busycotypus*

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by

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DEDICATION

I would like to dedicate this thesis to my loving parents, John and Joyce Shalack, and my amazing fiancée, Mary Lauren Hamrick. Their never ending support has help tremendously along the way.

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CHAPTER 1

INTRODUCTION

Four species of whelks (Family Melongenidae) are found in Georgia coastal waters; the knobbed whelk, *Busycon carica* (Gmelin 1791), the lightning whelk, *Busycon sinistrum* (Hollister 1958), the channeled whelk, *Busycotypus canalicalatus* (Linnaeus 1758), and the pear whelk, *Busycotypus spiratus* (Lamarck 1816). The Georgia Department of Natural Resources' Coastal Resources Division first authorized the commercial harvest of whelks in 1980 (Belcher et al. 2001). Annual landings peaked in 1990 at 462,196 kilograms of meat, with a value of $507,718 (GADNR 2006). However, in more recent years, landings have decreased significantly, to 28,842 kg in 2002 and 40,900 kg in 2003 and even further, to less than 1,814 kg for 2004 through 2006 (GADNR 2006).

The pattern displayed by Georgia's whelk fishery is not unique. Anderson et al. (1985) report a similar pattern in South Carolina's whelk fishery. Participation in the fishery increased steadily from 1978 to 1984, however yields peaked at 32,567 bushels (approximately 886,329 kg) in 1982 and by 1984 yields were a little over half of the 1982 numbers. The yields then fell below 7000 bushels (approximately 190,509 kg) a year from 1985 to 1990 (SCDNR 2005). The pattern then repeated again, rising from 1991 to 1995 to a little over 31,000 bushels (approximately 843,682 kg), then decreasing rapidly to below 9,000 bushels (244,940 kg) from 1998 to 2004 (SCDNR 2005).

Due to apparent over-fishing in Georgia waters, modifications to the current management scheme are needed in order to sustain whelk populations at commercially viable numbers. This may result in changes to one or more of the methods used to harvest whelks in Georgia: (1) trawling near shore with a modified shrimp net, (2) incidental harvest while shrimping, (3) blue crab (*Callinectes sapidus*, Rathbun 1896) traps, and (4) hand collecting in intertidal and shallow water areas (Walker 1988). Female whelks are significantly larger than males (Anderson et al. 1985, Walker 1988, Power et al. unpublished, Walker et al. unpublished); as a result whelk-trawls catch a disproportionate number of females (Anderson et al. 1985). The commercial whelk-trawling season may run from the end of December to April (Belcher et al. 2001) although other types of harvesting may occur throughout the year (Walker personal communication). However in 2006 the season opened in February and closed at the end of April (GADNR 2007). The commercial trawl fishery may result in the harvesting of mature females before oviposition.

Knobbed whelk oviposition occurs in spring (Magalhaes 1948, Kent 1983a, Walker 1988, Power et al. 2002, Walker et al. unpublished) and fall (Magalhaes 1948, Walker 1988, Castagna and Kraeuter 1994). Power et al. (2002) found copulation occurring in March followed by oviposition peaking in early April, which coincided with a dramatic increase in water temperatures. Females may be found mating with numerous smaller-sized males (Magalhaes 1948, Kent 1983a, Power et al. 2002). Often, several males awaiting an opportunity to mate will remain buried around the female in intertidal areas (Magalhaes 1948, Kent 1983a, Power et al. 2002). Recent genotypic data suggests the eggs are fertilized by multiple fathers from a well-blended pool of sperm (Walker et al. 2006). The eggs are then deposited within egg capsules attached in a series along an egg-case-string in the lower intertidal and subtidal areas (Walker 1988, Power et al. 2002).

The egg-case-string is anchored in the substrate by a series of modified empty egg capsules (Magalhaes 1948, Edwards and Harasewych 1988). The number of egg capsules on a string can vary greatly (Magalhaes 1948, Power et al. 2002). Magalhaes (1948), in North Carolina, found a range of 9 to 156 and Power et al. (2002), in Georgia, found a range of 40 to 157 for *Busycon carica.* The number of eggs per egg capsule can vary greatly as well (Magalhaes 1948, Power et al. 2002). Power et al. (2002) found that it ranged from 0 to 99 with the middle portion of the string generally containing larger capsules with more embryos. The egg capsules take anywhere from six weeks (Power et al. 2002) to several months (Castagna and Kraeuter 1994) to open. However, even though the capsules may open, many of the young may remain in the capsules, possibly using the structure as a refugium (Power et al. 2002).

Whelk reproduction can be affected by trawling as a result of their method of anchoring the egg strings in the substrate. Whelk-trawlers have reported pulling in egg strings especially during the spring (Anderson et al. 1985) and strings not caught in the net may be dislodged and subject to desiccation if washed ashore. This may lead to increased mortality of the eggs and/or juveniles remaining in the egg capsules.

Whelk reproductive behaviors occur during periods of generally increased intertidal activity. Whelk activity on the intertidal is at its greatest during the spring and fall (Magalhaes 1948, Kent 1983a, Walker 1988, Walker et al. 2004, Walker et al. unpublished) and lowest when water temperatures are at both their high and low extremes

(Walker 1988). The summer decrease may also be a result of increasing predation activity by stone crabs (*Menippe mercenaria*, Say) on whelks found on the oyster reefs (Kent 1983b). Hard clams, *Mercenaria mercenaria*, and oysters, *Crassostrea virginica*, are important food sources for whelks (Colton 1908, Warren 1916, Magalhaes 1948, Carriker 1951, Menzel and Nichy 1958, Peterson 1982, Walker 1988). Therefore, females may be moving to these areas to feed on the oysters and hard clams as a result of a higher demand of energy for reproduction (Walker et al. unpublished). Female whelks found in the intertidal zone may greatly outnumber males (Walker 1988, Walker et al. unpublished).

Certain behavioral patterns vary among the whelk species found on the intertidal zone. *Busycotypus canaliculatus* may be more active at night while *Busycon carica* and *Busycon sinistrum* may be active at all hours (Magalhaes 1948). Additionally, *B. carica* and *B. sinistrum* tend to be found higher in the intertidal zone than *B. canaliculatus* (Walker 1988). This may be a result of *B. carica* and *B. sinistrum* possessing a thicker 4 mm shell as opposed to *B. canaliculatus's* thinner 2 mm shell (Walker 1988). The shell thickness may also dictate feeding patterns. *B. carica* and *B. sinistrum* may use the edge of their own shell to chip and wedge their way into bivalve shells (Colton 1908, Warren 1916, Maglhaes 1948, Carriker 1951, Menzel and Nichy 1958, Paine 1962, Kent 1983b, Walker 1988) and rarely eat carrion (Walker et al. 2003). However, *B. canaliculatus* can be commercially caught in crab traps that are baited with carrion (Walker et al. 2003). *B. canaliculatus* may also feed on other gastropods (Magalhaes 1948).

Many ecological questions about whelk behavior in Georgia remain. Georgia's current whelk fishery is disproportionably targeting relatively slow-growing female whelks, possibly before oviposition (Walker personal communication). The trawling may also be increasing mortality of eggs and juvenile whelks as a result of dislodging egg-case-strings. With collapse of the offshore whelk fishery, interest in harvesting inshore whelk stocks has increased. The first study (Chapter 2) was designed examine issues pertinent to the sustainability of a whelk fishery in Georgia waters. It measures the trapping potential of whelks with various experimental and commercial traps in near shore waters. This data is necessary to accurately assess the current management strategy of the Georgia whelk fishery. The second study (Chapter 3) was designed to provide insight into the movement and behavioral patterns of whelks in the intertidal and subtidal zones. This information is necessary to understand the seasonal distribution changes in intertidal areas of Georgia's coast.

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CHAPTER 2

WHELK POT TRAPPING AND ITS IMPLICATIONS FOR INSHORE FISHERIES DEVELOPMENT[1]

[1] Shalack, J.D., R.L. Walker, and A.J. Power. To be submitted to *Journal of Shellfish Research*

Introduction

Four species of whelks (Family Melongenidae) are found in Georgia coastal waters; the knobbed whelk, *Busycon carica* (Gmelin 1791), the lightning whelk, *Busycon sinistrum* (Hollister 1958), the channeled whelk, *Busycotypus canalicalatus* (Linnaeus 1758), and the pear whelk, *Busycotypus spiratus* (Lamarck 1816). *B. carica* and *B. sinistrum* may use the edge of their own shell to chip and wedge their way into bivalve shells (Colton 1908, Warren 1916, Maglhaes 1948, Carriker 1951, Menzel and Nichy 1958, Paine 1962, Kent 1983, Walker 1988) and rarely eat carrion (Walker et al 2003). However, *B. canaliculatus* can be commercially caught in blue crab (*Callinectes sapidus*, Rathbun 1896) traps that are baited with carrion (Walker et al. 2003). *B. canaliculatus* may also feed on other gastropods (Magalhaes 1948). *B. spiratus* occur infrequently in Georgia waters (Walker 1988) but can be occasionally caught in crab traps (Walker et. al 2003).

The Georgia Department of Natural Resources' Coastal Resources Division first authorized the commercial harvest of whelks in 1980 (Belcher et al. 2001). Annual landings of whelk meat peaked in 1990 at 462,196 kilograms, valued at $507,718 (GADNR 2006). However, in more recent years, landings have decreased significantly, to 28,842 kg in 2002 and 40,900 kg in 2003 and down to less than 1814 kg for 2004 through 2006 (GADNR 2006). It is not clear whether the collapse is the result of fluctuations in whelk populations or reduced fishing effort (GADNR 2007b).

The majority of whelk fishing occurs in the offshore areas of Georgia with the inshore blue crab fishers harvesting channeled whelks that entered crab traps as a by-product of that fishery. Currently there is not a limit on the size of whelks that can be harvested in Georgia waters (GADNR 2007a). However, there generally is a limit to the size of whelks, usually less than 150 mm in length, that a processor deems not economical to process (Power personal comm.). With the collapse of the offshore fishery, an increased interest in harvesting whelks from inshore areas has developed.

Female whelks are significantly larger than males (Anderson et al. 1985, Walker 1988, Power et al. unpublished, Walker et al. unpublished); as a result whelk-trawls catch a disproportionate number of females to males (Anderson et al. 1985). This is a result of the size selection of the large 10.16 cm stretch mesh webbing nets that the trawlers are required to use. The commercial offshore whelk-trawling season usually occurs January through March (GADNR Commissioner determines actual dates of opening and closing) in Georgia with intertidal hand gathering and crab trapping harvesting occurring throughout the year (Walker personal communication). This may result in the harvesting of mature females before oviposition. Whelk-trawlers may pull in anchored egg-case strings while fishing, especially during the spring (Anderson et al. 1985). The strings are discarded overboard and thus subject to desiccation if washed ashore. This increases mortality of the eggs and/or juveniles remaining in the egg capsules. Intertidal hand gathering may also bias collection of female whelks as Walker (1988) found that females greatly outnumber males on the intertidal flats in Georgia, with ratios reaching 11 to 1.

Traditionally, Georgia has not had a pot fishery for channeled whelks as exists in more northern states (Shaw 1960). At the request of industry, the Marine Extension Service has begun to investigate the feasibility of establishing an inshore fishery for whelks, as well as determining the biological data needed to successfully manage such a fishery. Walker et al. (2003) compared the efficiency of standard crab traps and

Chesapeake Bay conch pots in catching whelks in the Wassaw Sound, GA. They found no significant difference, although the standard crab trap consistently caught more whelks. They caught more whelks using a combination bait of Atlantic Menhaden (*Brevoortia tyrannus,* Latrobe 1802) and blue crab than either bait type alone. This paper further examines the feasibility of a commercial whelk pot fishery in Georgia coastal waters. It examines the efficiency of four experimental trap designs as compared to the standard blue crab trap.

Materials and Methods

Study Area

The study occurred in two locations 1) off Dead Man Hammock, Wassaw Island in Wassaw Sound, GA and 2) in Beard Creek on the south side of Wilmington Island, GA (Figure 2.1). The Wassaw Sound Site is approximately 300 meters from the shore of Dead Man Hammock in the Wassaw Island National Wildlife Refuge. Water depth at low tide is approximately 3-4 meters. The substrate is mostly muddy sand. The Beard Creek site is a salt marsh tidal creek running through an area of extensive salt marsh. The creek is approximately 30 meters wide at its entrance. Oyster reefs can be found intertidally, scattered along the length of the creek. Water depth is approximately 3-4 meters at low tide. The substrate was mostly muddy.

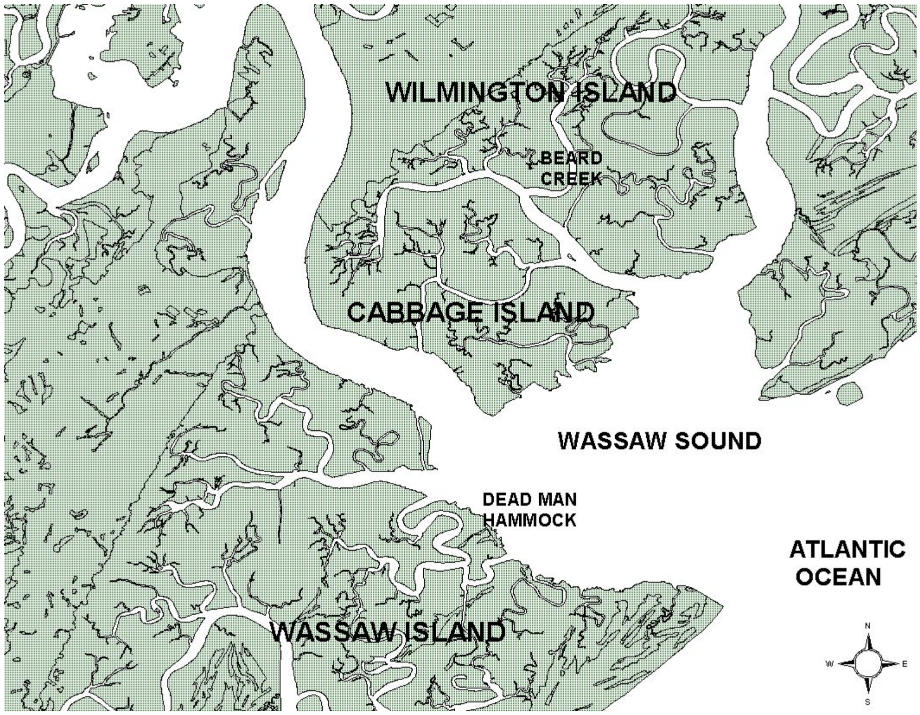

Figure 2.1. Dead Man Hammock and Beard Creek study sites.

Study Design

Analysis of whelk harvest potential and pot efficiency occurred from May 10, 2006 to June 27, 2006. Four different experimental traps (modified crab trap, alcohol container trap, plastic pyramid trap, and mesh pyramid trap) were compared for catch efficiency against a standard crab trap (control) (Figure 2.2). One of each type of trap, spaced 10 meters apart, was randomly assigned to a line (no alcohol container traps in Beard Creek lines). Crab floats were attached to each end of the long line to aid in retrieval. Four lines of traps were deployed at each of the two study sites. Traps were baited with Atlantic Menhaden (*Brevoortia tyrannus,* Latrobe 1802) and blue crab (*Callinectes sapidus,* Rathbun 1896). Traps were checked and rebaited every two days (except for two 3 day soaks when checks were postponed due to weather conditions and boat problems). At each sampling, the whelks in each trap were placed into prelabeled buckets. Captured organisms (other than whelk) were identified and released approximately 1 km from harvest areas to prevent recaptures. The collected whelk were transported to the University of Georgia Marine Extension Service Shellfish Research Laboratory at Skidaway Island, GA for further data collection and to be placed in holding facilities until the end of the trapping experiment. For each sample, whelk species was identified, its shell length (apex to siphon canal), shell width (across shoulder), weight, and sex (by presence or absence of a penis) was recorded and a Hallprint tag (type FPN, Holden Hill, Australia) was applied to the shoulder whorl of each whelk. At the end of the study, the captured whelks were released at the site of harvest.

Trap Design

Standard crab trap (Figure 2.2)

The trap was a 60 x 60 x 60 cm cube made of 3.8 cm vinyl-coated wire mesh. It had four 16.5 cm funnels, one on each of the sides for organisms to enter. A wire mesh bait box was attached to the center of the trap. One centimeter diameter steel rebar was attached to the bottom of the trap to aid in sinking and provide resistance to movement in currents.

Modified crab trap (Figure 2.2)

Polypropylene (1.6 mm thickness) was cut to the shape of the funnel and attached to a standard crab trap. The plastic was attached to the bottom half of each funnel entrance and in front of the funnels to the bottom of the trap.

Alcohol container trap (Figure 2.2)

A 15 centimeter diameter hole was cut in the top of a plastic 18.9 liter ethanol container. One centimeter mesh netting was attached around the opening at the top to prevent whelk from crawling out. Two centimeter holes were drilled in the sides of the container to aid in dispersion of chemical cues from the bait. A 2.54 cm layer of concrete was poured in the bottom of the trap to aid in sinking and provide resistance to movement in currents. A wire mesh bait box was attached to the inside bottom of the trap. This trap is representative of traps currently used in the commercial *Buccinum undatum* fishery in Ireland (Power et. al. 2002).

Plastic pyramid trap (Figure 2.2)

The trap was 60 x 60 cm at the base and 20 cm tall pyramid covered in 1.6 mm polypropylene. The bottom of the trap was covered with 1 cm plastic mesh. The frame was made of 1.27 cm (1/2 inch) pvc tubing. The opening at the top was 15 x 15 cm with 3 cm of plastic extending down into the hole to prevent whelks from crawling out. Two centimeter holes were drilled in the sides of the trap to aid in dispersion of chemical cues from the bait. Two wire mesh bait boxes were attached to the inside bottom of the trap on opposing sides. One centimeter diameter steel rebar was attached to the bottom of the trap to aid in sinking and provide resistance to movement in currents.

Mesh pyramid trap (Figure 2.2)

The trap was the same as plastic pyramid trap except 3.8 cm vinyl-coated wire mesh was used in place of the 1.6 mm polypropylene.

Figure 2.2. Standard crab trap (top left), Modified crab trap (top right), Alcohol container trap (middle left), Plastic pyramid trap (middle right), Mesh pyramid trap (bottom left).

Data Analysis

Data was analyzed using SAS and R. Chi-squared tests (α=0.05) were used to evaluate global significant differences in whelk catches between study sites and traps. Poisson models were built to evaluate significant differences in number caught by location and traps by individual species. A generalized linear model was built to evaluate whelk weights by location and trap type with the Beard Creek site and plastic pyramid serving as baseline values.

Results

A grand total of 734 whelks [350 channeled (47.7%), 255 knobbed (34.7%), 129 pear (17.6%)] were caught from May 10, 2006 to June 27, 2006 (total of 24 harvesting sessions) (Table 2.1). One of the lines of traps at the Dead Man Hammock site was lost after the 14th harvesting session (June 3, 2006). For channeled whelks, Chi-squared tests indicate that no significant difference occurred between locations ($p=0.1038$), but there was a significant difference in trap type ($p<0.0001$). For knobbed whelks, Chi-squared tests indicated no significant difference between locations ($p=0.3481$) or trap type ($p=0.0625$). There was a significant difference in trap type ($p<0.0001$) for pear whelks, but none were caught at the Beard Creek site.

Table 2.1. Total number of whelks caught at Dead Man Hammock and Beard Creek study sites.

	Species			
	Channeled	Knobbed	Pear	**TOTAL**
Dead Man	156	106	129	**391**
Beard Creek	194	149	0	**343**
TOTAL	**350**	**255**	**129**	**734**

Overall, there were 318 females, 325 males, and 91 unknown whelks caught (Table 2.2). The Pearson's Chi-squared showed that there was no significant difference ($p=0.1118$) in sex among trap types or lines ($p=0.0599$). However, significantly more ($p=0.0063$) males occurred at Dead Man Hammock whereas more females occurred in

Beard Creek. For both sites, there was no significant difference (Chi-squared) in sexes for channeled and pear; however there was a significant difference for knobbed at Dead Man Hammock (Table 2.2).

Table 2.2. Total number of male and female whelks caught at Dead Man Hammock and Beard Creek. Chi-squared significance value is 3.84.

	Species	Females	Males	Unknown	p-value
Dead Man	Channeled	61	71	24	0.758
	Knobbed	37	59	10	5.04*
	Pear	42	47	40	0.281
	TOTAL	**140**	**177**	**74**	
Beard Creek	Channeled	98	86	10	0.783
	Knobbed	80	62	7	2.28
	TOTAL	**178**	**148**	**17**	
GRAND TOTAL		**318**	**325**	**91**	

* Significantly higher than x^2 value of 3.84

Length, width, and weight were found to be closely correlated (Pearson). Lengths and weight data for the whelks caught are found in Table 2.3. The results of a generalized linear model for channeled whelk average weight showed that a significant difference ($p<0.0001$) occurred between locations with Beard Creek being significantly heavier. For knobbed whelks, there was a significant difference ($p<0.0001$) in average weight by location with Dead Man Hammock being heavier. No pear whelks were caught in Beard Creek.

Table 2.3. Length and weight data for whelks caught.

	Species	Total Number	Length (mm)		Weight (g)	
			Mean ± Std. Dev.	Range	Mean ± Std. Dev.	Range
Dead Man	Channeled	156	84.7 ± 19.2	42 - 155	39.7 ± 29.22	6 - 273
	Knobbed	106	91.7 ± 22.7	60 - 170	101.7 ± 92.24	28 - 586
	Pear	129	76.9 ± 12.07	49 - 122	28.5 ± 13.51	6 - 92
Beard Creek	Channeled	194	94.98 ± 15.41	53 - 159	54.47 ± 29.8	10 - 228
	Knobbed	149	75.66 ± 14.23	37 - 116	46.78 ± 24.62	12 - 130

In total the plastic pyramid trap caught more whelks than any other trap (Table 2.4). The alcohol container trap caught the least of any trap in total but was only deployed at the Dead Man Hammock site (Table 2.4). No knobbed whelks were caught in the alcohol container traps (Table 2.4).

Table 2.4. Total numbers of whelks caught by the study traps (alcohol container trap= A, standard crab trap= CT, modified crab trap=MC, mesh pyramid trap=MP, and plastic pyramid trap=PP).

		Trap					
	Species	**A**	**CT**	**MC**	**MP**	**PP**	**Total**
Dead Man Hammock	Channeled	33	29	27	10	57	**156**
	Knobbed	0	24	49	12	21	**106**
	Pear	30	10	12	12	65	**129**
	Total	**63**	**63**	**88**	**34**	**143**	**391**
Beard Creek	Channeled	N.A.	32	61	24	77	**194**
	Knobbed	N.A.	15	39	29	66	**149**
	Total	N.A.	**47**	**100**	**53**	**143**	**343**
Total All	Channeled	33	61	88	34	134	**350**
	Knobbed	0	39	88	41	87	**255**
	Pear	30	10	12	12	65	**129**
	Total	**63**	**110**	**188**	**87**	**286**	**734**

In general the traps with the plastic surfaces caught more whelks than the traps having only the 3.8 cm vinyl-coated mesh (Table 2.5). The traps having 3.8 cm vinyl-coated mesh generally had higher average catch weights than traps with plastic outside walls (Table 2.5). The performance of the traps by average weight caught and total number caught is listed in Table 2.5.

Table 2.5. Order of traps in terms of average weight and total number caught for each species (alcohol container trap= A, standard crab trap= CT, modified crab trap=MC, mesh pyramid trap=MP, and plastic pyramid trap=PP)

	Average Weight			Total Number		
	Channeled	Knobbed	Pear	Channeled	Knobbed	Pear
Highest	CT (<0.0001*)	MC (<0.0001*)	CT (<0.0001*)	PP	MC (0.9719)	PP
	MC (<0.0001*)	CT (0.0059*)	MC (<0.0001*)	MC (0.0563)	PP	A (0.024*)
	MP (0.0302*)	PP	MP (<0.0001*)	A (0.098)	MP (0.0642)	MC (<0.0001*)
	PP	MP (0.1472)	A (0.042*)	CT (0.0003*)	CT (0.0523)	MP (<0.0001*)
Lowest	A (0.3584)	A (N.A)	PP	MP (0.0001*)	A (N.A)	CT (<0.0001*)

*Significantly different from the plastic pyramid trap

A total of 176 blue crabs (*Callinectes sapidus*) were caught at both locations (Table 2.6). More blue crabs were caught at the Dead Man Hammock site than at the Beard Creek site (Table 2.6). The standard crab trap and the modified crab trap caught more than the other traps (Table 2.6).

Table 2.6. Total numbers of blue crabs (*Callinectes sapidus*) caught by study traps (alcohol container trap= A, standard crab trap= CT, modified crab trap=MC, mesh pyramid trap=MP, and plastic pyramid trap=PP)

	Trap					
	A	CT	MC	MP	PP	**Total**
Dead Man	6	65	62	11	8	**152**
Beard Creek.	N.A.	11	12	1	0	**24**
Total	**6**	**76**	**74**	**12**	**8**	**176**

Total whelk catches per harvesting session were quickly reduced during the study. At the Dead Man Hammock site total catches of whelks per day dropped below 20 after only three weeks and never recovered (Figure 2.3). At the Beard Creek site, after an initial high within the first week of fishing, the numbers caught dropped to less than 15 for the rest of the study (Figure 2.4).

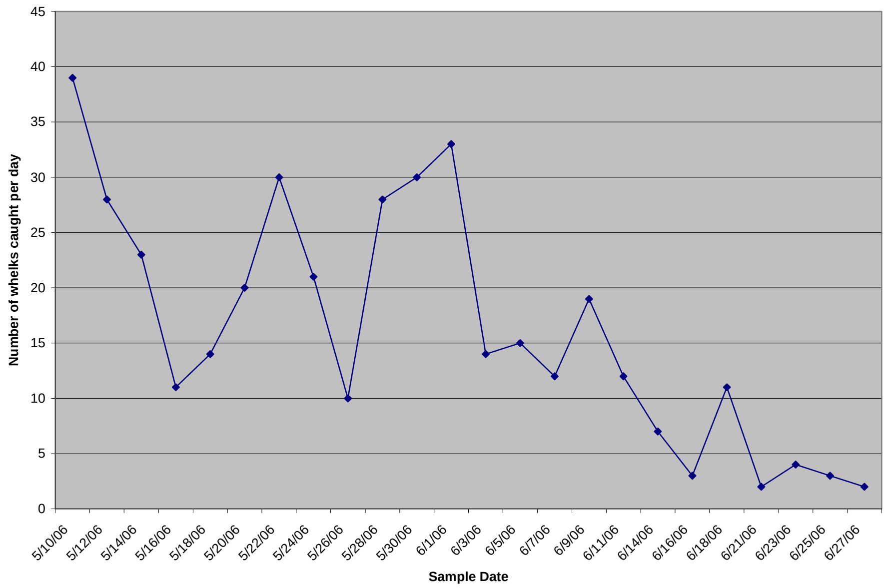

Figure 2.3. Total number of whelks caught during study at the Dead Man Hammock site.

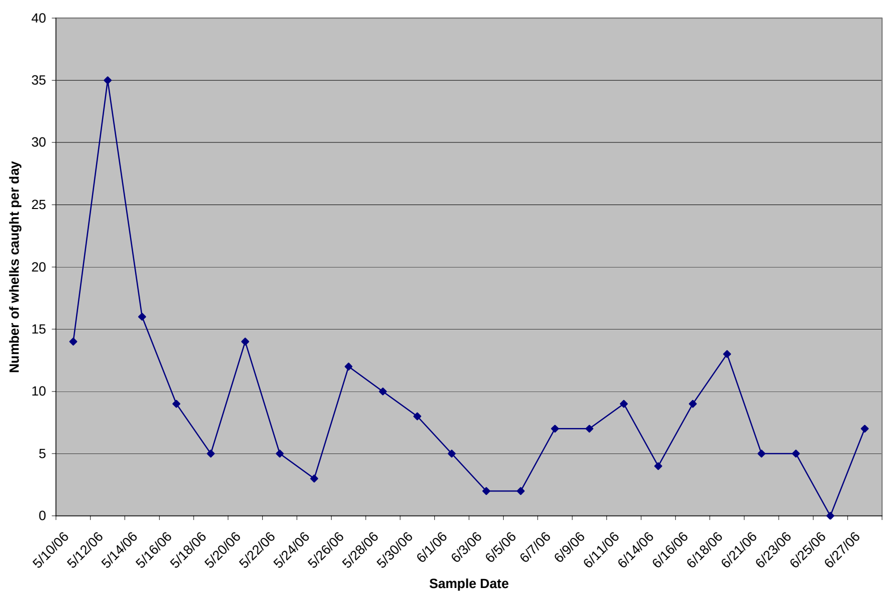

Figure 2.4. Total number of whelks caught during study at the Beard Creek site.

Discussion

A greater number of channeled whelks were caught compared to other species of whelks. Channeled whelks are known to eat carrion (Walker et al. 2003) and make up the majority of the whelks caught in pot fisheries along the eastern coast of the United States (Shaw 1960, Logothetis and Beresoff 2004). Walker et al. (2003) who worked in the same sound as this study and Logothetis and Beresoff (2004) who worked in near shore waters in North Carolina also caught more channeled whelks than other species in pot trapping experiments. However, the proportion of channeled whelks caught in this study is quite different. Walker et al. (2003) caught 89% channeled whelks and Logothetis and Beresoff (2004) trapped 99% channeled as opposed to the 47.7% channeled caught in this study.

This difference becomes especially apparent when just looking at the more oceanic study site, Dead Man Hammock. In a similar area of the same sound, Walker et al. (2003), also reported catches of 6.1% knobbed, 4.3% pear, and 0.5% lightning. Although they were using only traps with 3.8 cm (1.5 inch) gaps (similar the standard crab trap, modified crab trap and mesh pyramid trap in this study), which may cull out smaller sized whelks, it does not account for the lower percentage of channeled whelks caught in this study. The percentage caught at the Dead Man Hammock was 35.6%, 46%, and 18.4% for channeled, knobbed and pear respectively, when the catches of the alcohol trap and the plastic pyramid trap (traps without 3.8 cm gaps) are removed. The difference in smooth surfaces (plastic surfaces) for foot attachment by the whelks does not seem to account for the difference either as the catches are 40.2%, 37.1%, and 22.7% for channeled, knobbed, and pear, respectively when only the standard crab trap and the mesh pyramid trap totals are calculated.

Water temperatures may have been a factor for the reduced percentage of channeled whelks caught. Walker et. al. (2003) trapped whelks during late March to

April and Logothetis and Beresoff (2004) worked from November to March. Water temperatures may have been significantly warmer during this study than the others, as it was performed from mid-May to late June. Whelk pot fisheries in cooler waters, in more northern states on the east coast such as Delaware and Massachusetts, consistently catch more channeled whelks than knobbed whelks in pot fisheries. The warmer temperatures may have resulted in greater activity of the knobbed and pear whelks or a lessening of activity from the channeled whelks. Knobbed whelks can be found abundantly on intertidal areas during the spring but are generally absent during summer (Walker 1988). The knobbed whelks may be moving to deeper subtidal areas, where the traps were located, as air and water temperatures increased. Channeled whelks are known to feed in temperatures ranging from 15.6 to 22.2 ºC in Massachusetts (Shaw 1960). Polites and Mangum (1980) found that in Virginia, channeled whelks behave abnormally above 23 ºC and become conspicuously sluggish at 24 ºC. Water temperatures in Wassaw Sound during this study reached these temperatures around May 22 (Figure 2.5).

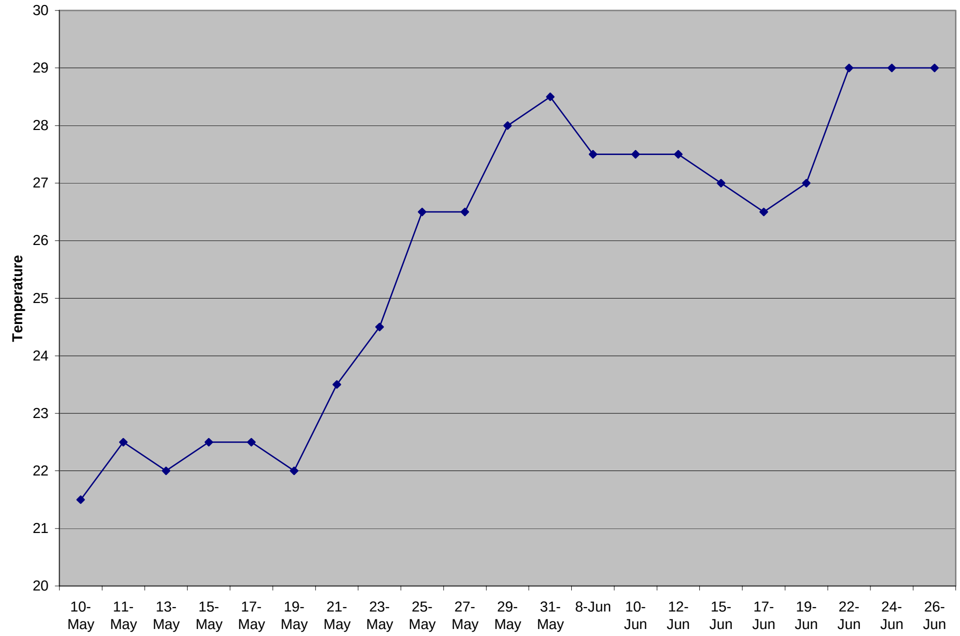

Figure 2.5. Water temperatures (ºC) in Wassaw Sound during study.

It is likely that channeled whelks found in Georgia are slightly more adapted to higher water temperatures than channeled whelks found in more northern areas, but Georgia is near the southern end of the channeled whelks' range (Abbott 1974). Therefore, it is likely that the summer month water temperatures in Georgia are approaching the physiological limit for channeled whelks.

At both sites, Dead Man Hammock and Beard Creek, the traps with smooth plastic surfaces caught more whelks than solely mesh wire traps (standard crab trap and mesh pyramid trap). The smooth surface may provide more surface area for a whelk's foot to securely attach to the trap as it crawls. The Georgia coast has a relatively high tidal range from 2-3 meters between low and high tide. Therefore, tidal currents can be rather swift along the Georgia coast. This may increase the importance of the available foot attachment surface area on the traps.

Most (80.8%) of the whelks caught were less than 100 mm in total length. The 38 mm wire mesh covering the standard crab trap and the mesh pyramid might have hindered the foot attachment of smaller whelks. This may have prevented some whelks from entering the wire mesh covered traps. The modified crab trap was also covered in the wire mesh, but the modifications to the funnel entrance with pieces of plastic provided a foot attachment site for the smaller whelks.

The mesh coverings may also explain the average catch weights. For channeled and pear whelks, the standard crab trap had the highest average catch weights, followed by the other two traps with mostly large mesh coverings (modified crab trap and mesh pyramid). For knobbed whelks the overall order was similar with the modified crab trap standard crab trap having the highest average catch weights. The larger mesh size may have had a combination affect on the size of the whelks caught; 1) it prevented smaller sized whelks from effectively entering the trap and 2) allowed even smaller whelks that did manage to enter the trap, to fall out as the trap was being lifted into the boat.

Total numbers of whelks collected during each harvest quickly declined. The quick depletion of whelk populations in an area is not unusual. Shaw (1960) reports catching more than 80 percent of total catch within the first two weeks in trapping experiments in Massachusetts. Walker et al. (2003) showed that catch rates for channeled whelks dropped from an initial mean of approximately 32 per crab trap to less than 5 per trap by week four of trapping. By week four most potted whelks were ones that had been caught, tagged, released some 200 meters away and had re-entered the trapping site. The quick depletion combined with most (80.8%) of the trapped whelks being less than 100 mm in length makes the probability of a commercially viable whelk potting fishery in Georgia unlikely.

Although the plastic pyramid trap caught the greatest number of whelks (40% of total catch), most of the whelks were relatively small. The modified crab trap caught the second greatest number of whelks and had the highest average catch weight for knobbed whelks and the second highest for channeled and pear whelks. Probably the most commercially effective way of potting whelks in Georgia is as a combined fishery with the current blue crab fishery. By adding plastic to the funnel entrance of current crab traps, crabbers can increase the number of marketable size whelks caught by the standard crab traps currently in use.

This study does not address several questions which must be addressed before establishing a commercial fishery. It does not address whether the whelk harvest would be viable for multiple years in the same locations. It is also not clear that an inshore trap fishery would be sustainable at viable commercial levels. In Georgia, knobbed whelk males reach sexual maturity at 85 to 90 mm in 4 years and females at 100 mm in 6 years (Power personal communication). However, the size and time needed to attain sexual maturity for channeled whelks is still unknown. Also, it is unclear how often a female knobbed or channeled whelk lays eggs in Georgia. Until these questions can be address, a sustainable as well as commercially viable harvest level cannot be set.

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CHAPTER 3

MOVEMENT AND BEHAVIOR OF THE KNOBBED WHELK, *BUSYCON CARICA* (GMELIN 1791), ON INTERTIDAL FLATS IN WASSAW SOUND, GA[1]

[1] Shalack, J.D., R.L. Walker, and A.J. Power. To be submitted to *Journal of Shellfish Research*

Introduction

The knobbed whelk, *Busycon carica* (Gmelin 1791), can be readily found in intertidal areas of the southeastern United States during spring and fall (Magalhaes 1948, Walker 1988, Walker et al. 2004). Females can often be found mating with numerous smaller-sized males in intertidal areas during these periods (Magalhaes 1948, Power et al. 2002). Overall, female whelks greatly outnumber males on the intertidal flats in Georgia, with ratios reaching 11 to 1 (Walker 1988). The spring and fall is also the peak of ovipostion for *B. carica* (Magalhaes 1948, Walker 1988, Castagna and Kraeuter 1994, Power et al. 2002).

Observations of *Busycon carica* suggest that movement between shallow and deep waters is associated with reproduction and perhaps food supply (Magalhaes 1948). *B. carica* are known to be predators on live bivalves such as the hard clam, *Mercenaria mercenaria* (Linnaeus 1758) and oysters, *Crassostrea virginica* (Gmelin 1971) (Colton 1908, Warren 1916, Magalhaes 1948, Carriker 1951, Menzel and Nichy 1958, Peterson 1982, Walker 1988). They can use the edge of their relatively thick edged shell, 4mm (Magalhaes 1948), to chip and wedge their way into closed bivalves (Colton 1908, Warren 1916, Maglhaes 1948, Carriker 1951, Menzel and Nichy 1958, Paine 1962, Walker 1988). In Georgia waters, hard clams and oysters inhabit the intertidal areas (Walker and Tenore 1984, Harris 1980, respectively). Therefore, the intertidal areas in Georgia waters harbor an important source of prey for *B. carica*.

In coastal Georgia waters, knobbed whelks are absent from intertidal areas during daytime in summer and winter months when average temperatures are at the most extreme (Walker 1988). They can survive when placed in intertidal areas during these periods by burying in the sediment, but it is uncertain whether they would stay in the area by choice (Walker et al. 2004). *Busycon carica* released in the middle intertidal region during the winter immediately buried and did not move until water temperature increased to 14ºC (Walker et al. 2004). As whelks began to move, they followed the contours of oyster reefs, from the rear of an intertidal inlet, towards the lower intertidal and subtidal area (Walker et al. 2004).

Busycon carica movement varies greatly. They may be active for several days and then inactive for a longer period of time (Magalhaes 1948). Magalhaes (1948) reported single day movements of fifteen to forty meters. She also reported laboratory movement rates varying from 0.83 mm s^{-1} to 1.67 mm s^{-1}. Ferner (2006) reported a speed of 0.5 mm s^{-1} while tracking prey odor plumes in a laboratory flume.

This study attempts to provide a more detailed picture of *Busycon carica* movement and behavior on intertidal areas of the Georgia coasts. Although it has been shown that *B. carica* can survive in the middle intertidal region in summer or winter months (Walker et al. 2004), this study hopes to answer whether they stay in the area by choice and if so, do they remain active or just stay buried until environmental conditions become more favorable.

Materials and Methods

Study Area

The study was conducted at Dead Man Hammock at Wassaw Island in Wassaw Sound, GA (Figure 3.1). An extensive oyster reef having numerous inlets runs along the length of the Hammock. The reef runs from the northeastern end of Dead Man

Hammock to Old Romerly Marsh Creek. The reef is well formed in some areas but becomes quite patchy in some of the inlets. Below the oyster reef, a muddy-sandy substrate may extend approximately 300 meters out into the sound from the oyster reef at spring low tide. Hard clams occur to a lesser extent amongst the oysters.

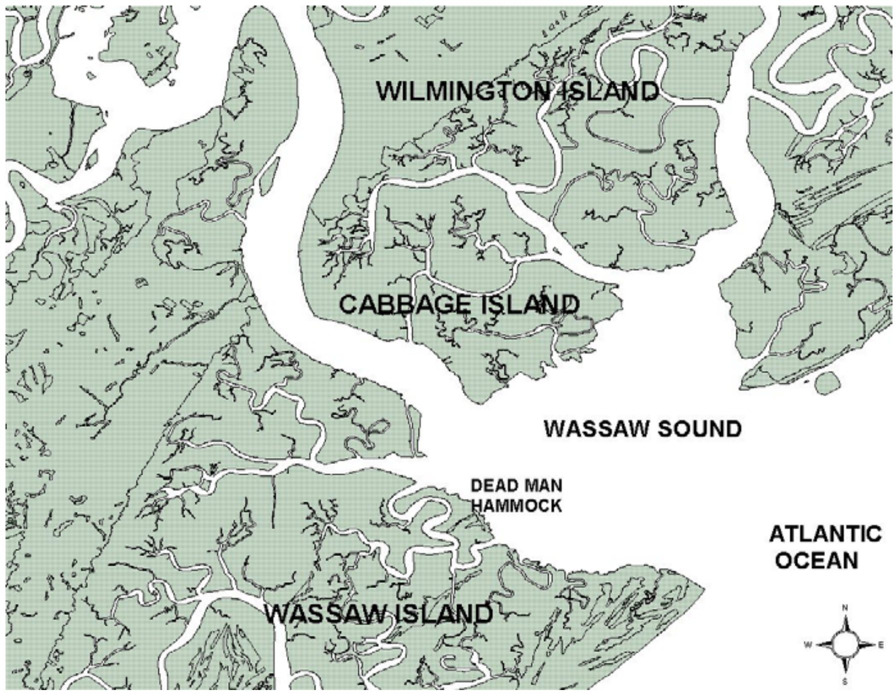

Figure 3.1. Dead Man Hammock study site in Wassaw Sound, GA.

Study Design

Whelks were collected from the Dead Man Hammock area. The shell length (apex to siphon canal), shell width (across shoulder), and weight were recorded for each animal. The whelks were placed in seawater containing 7% magnesium chloride to relax the organism and sex was determined by the presence or absence of a penis. Each organism was then individually tagged with Hallprint tags (type FPN, Holden Hill, Australia) for identification. A 2x3 cm piece of galvanized aluminum flashing was also attached to the dorsal area of the shell, with J-B Weld Kwik, to allow detection by a metal detector (Minelab Excalibur 800) (adapted from Walker et al. 2004).

Tagged *Busycon carica* (25 males and 25 females) were released on April 11, 2006, during low tide, at a vertical PVC pole placed at the rear middle of an oyster reef inlet (Figure 3.2). Tracking occurred daily for the first 14 days and then every other day until August 7, 2007 when the tide recession permitted. Most (94%) tracking of movement occurred during daylight low tides (3 nighttime). When a whelk was located, its distance (by measuring tape) and compass direction (by handheld magnetic compass) to the release point was determined. The whelks position (surface, partially buried, completely buried) and activity (mating, feeding, etc.) was also noted.

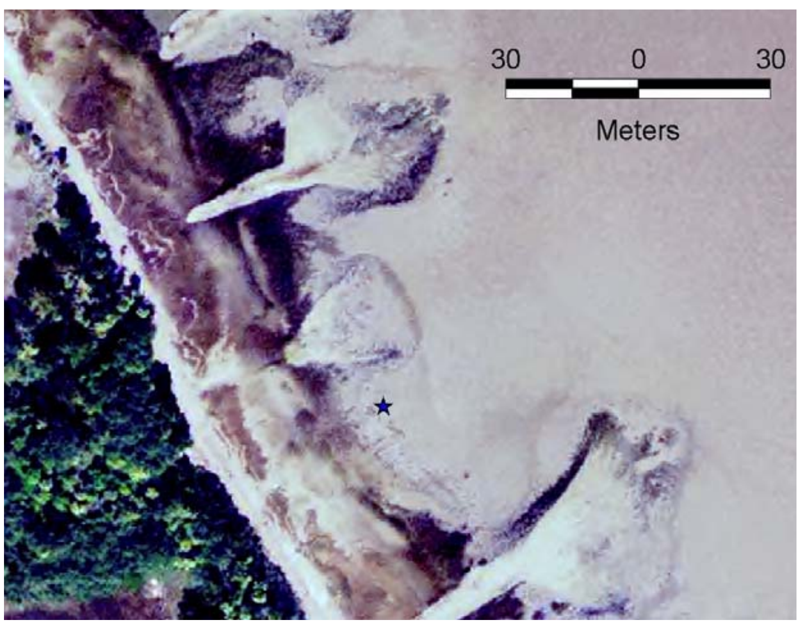

Figure 3.2. Dead Man Hammock study inlet with release point denoted by a star.

Over time, whelks became increasingly more buried, so on July 2, 2007 a separate counting method of all visible (not buried) whelks was started. All visible whelks (including untagged whelks) were counted along a 55 meter contoured length of the oyster reef on the right side of the study inlet. Whelks on the oyster reef and out to 5 meters from the edge of the oyster reef on mud substrate boundary were counted.

Data Analysis

The release point UTM coordinates were determined using the averaging function on 1200 readings from a Garmin GPS 72. Whelk compass locations were corrected 6° W for magnetic declination from true north according to calculations by the National Geophysical Data Center. Whelk distances and directions from the release point were converted into UTM coordinates using ESRI ArcView GIS 3.2 with the extension Bearing Maker v1.1. The coordinates were then used to create a shapefile. The point shapefile was layered on a georeferenced aerial photograph from the Savannah Chatham County Metropolitan Planning Commission (January 2004). Movement paths and the minimum convex polygon shapefiles were created by the extension Animal Movement v2. Minimum average daily movement was calculated between every two consecutive whelk locations. The minimum distance between the points was divided by the number of days between the locations providing an average minimum daily movement rate for the segment. SAS/STAT 9.1 was used for statistical analysis of minimum daily movement.

Results

Tracking Totals

Fifty whelks (25 males, 25 females) were release on April 11, 2006. The males ranged in length from 78 mm to 118 mm (mean 96.4 ± 12.1 mm) and females from 121 mm to 222 mm (mean 160.1 ± 21.5 mm). Tracking occurred 48 days and 3 nights (total = 51) from April 12 to August 7, 2006. Water temperatures ranged from a low of 20.5ºC to a high of 31ºC and air temperatures from 18ºC to 34ºC during the tracking (Figure 3.3).

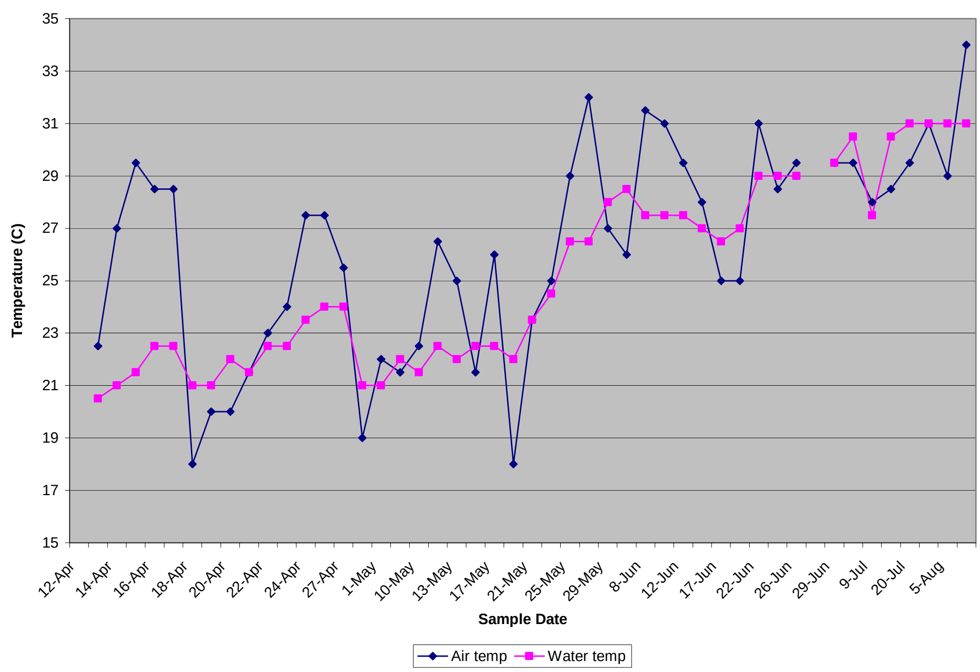

Figure 3.3. Air and water temperatures (°C) at Dead Man Hammock.

A total of 680 whelk locations were recorded (261 male, 419 female). The number of sightings for individual whelks ranged from 0 to 42 locations (mean 13.6 ± 9.1, median 11). In 356 instances, the whelks were completely buried, 253 partially buried, 69 on the surface and 2 unknown (not recorded). The greatest movement recorded was 52.9 m d^{-1}. A minimum convex polygon around all of the located whelk positions encompassed an area of 7064.3 m^2.

After release, whelks randomly spread out away from the release point over the intertidal mud flat. By day 8 after release, whelks began concentrating on and near live oyster reefs (Figure 3.4). Over the entire study the majority of whelk sightings were made on or near live oyster reefs (Figure 3.5).

Figure 3.4. Whelk positions on day 1-6, 8, and 9 respectively, after release. Release point denoted by a star.

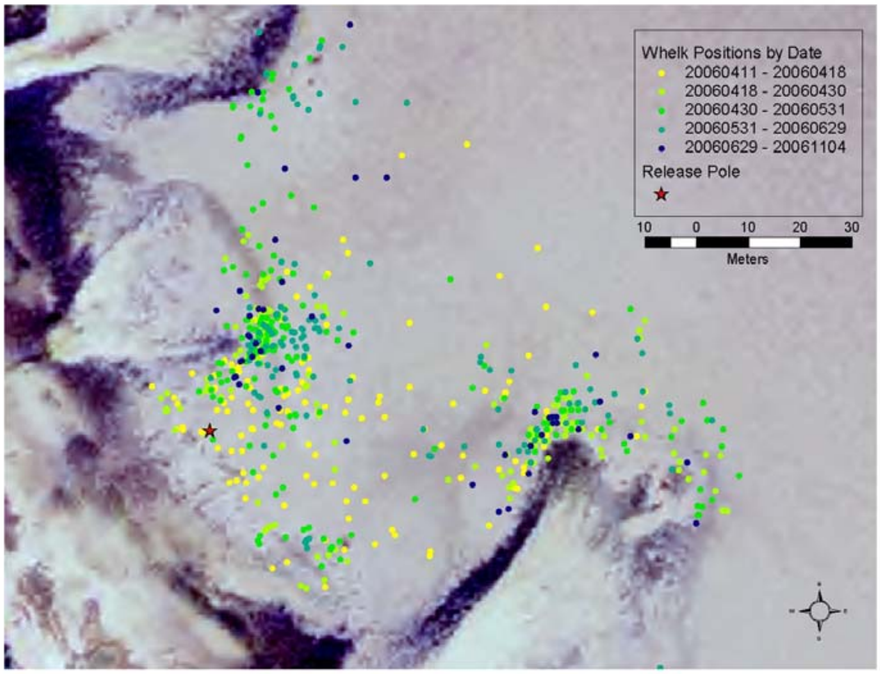

Figure 3.5. All whelk locations at study site, Dead Man Hammock.

As the study progressed fewer whelks were being located. In May, 38 individuals were identified as still in the study inlet. By June, 32 of the whelks could be accounted for; and then by July the number had declined to 23. By completion of the tracking, 1 whelk had never been located, 9 were still within the tracking area, and 9 were confirmed dead (4 males, 5 females). Twenty-four of the whelks had been within 30 meters of the edge of the search area when the whelk was last located [4 at near center of inlet (Figure 3.6), 5 around left side oyster reef and 15 around the right side oyster reef (Figure 3.7)] and presumably moved out of the area. The remaining 7 whelks were greater than 50 meters from the edge of the search area at their last sighting and were presumably lost (by unaccounted predation, loss of metal flashing, or some other means) in the search area.

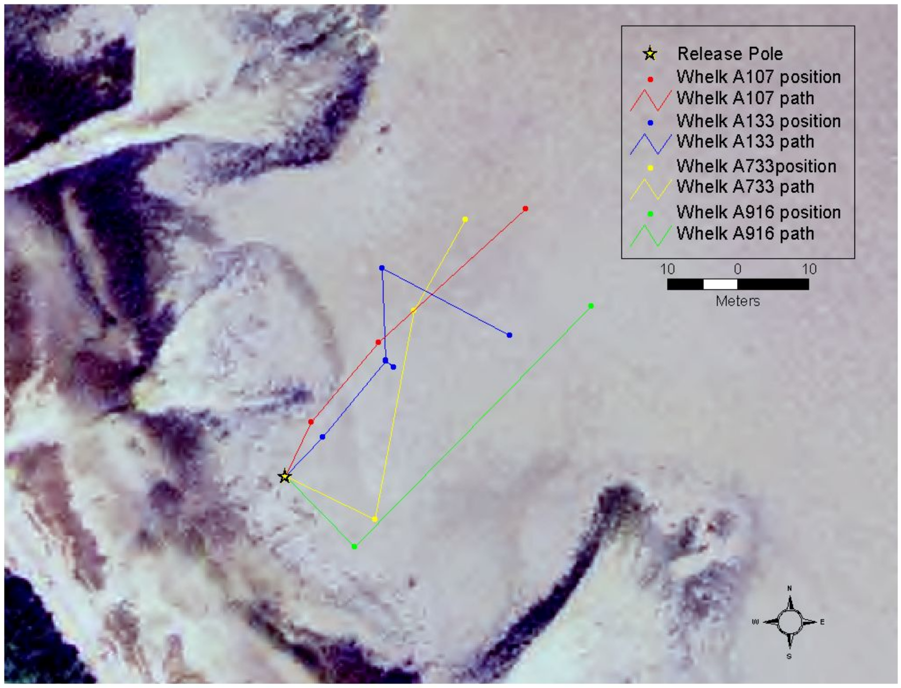

Figure 3.6. Whelks moving in center of inlet leading to last known location.

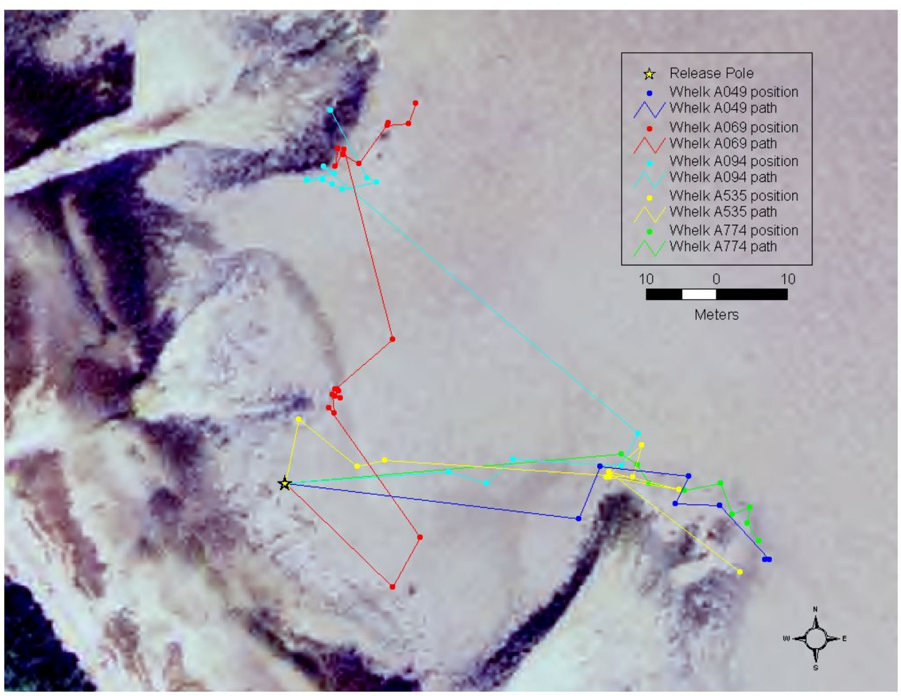

Figure 3.7. Whelks moving around oyster reefs leading to last known location

Movement and Positions

The mean individual minimum (assumes straight movement path) daily movement rate was not significantly different (Tukey's studentized range $\alpha=0.05$) for 41 of the 49 located whelks. Six of the 49 whelks were significantly faster than the group of 41. One female whelk movement was significantly greater than all others, but was based on only one movement segment. The grouping of the 41 whelks that did not display significant differences in movement had mean individual minimum daily movement rates that ranged from 0.66 to 6.05 m d^{-1}. Female minimum daily movement ranged from 0.0 m d^{-1} to 52.9 m d^{-1} and male from 0.0 m d^{-1} to 42.2 m d^{-1}. For males vs. females, the minimum average daily movement rate was significantly lower (ANOVA $p<0.0001$) for males (mean 1.61 m d^{-1}) than females (mean 2.57 m d^{-1}).

Early in the study, whelks tended to be on the surface or only partially buried (exposed), but later in the study most of the whelks located were found completely buried (not exposed) (Figure 3.8). In April, significantly more (Chi squared $\alpha=0.05$) whelks were partially or completely exposed when located on 7 of the 16 tracking days versus 1 of the 16 that significantly favored completely buried. From May to August, significantly more whelks were found buried on 12 of the 32 tracking days (Figure 3.9). Significantly more (Chi squared $\alpha=0.05$) female whelks' locations were made than male whelks' locations for each of the periods. Exposed females outnumbered males 2.51:1 during April and 2.55:1 from May to August.

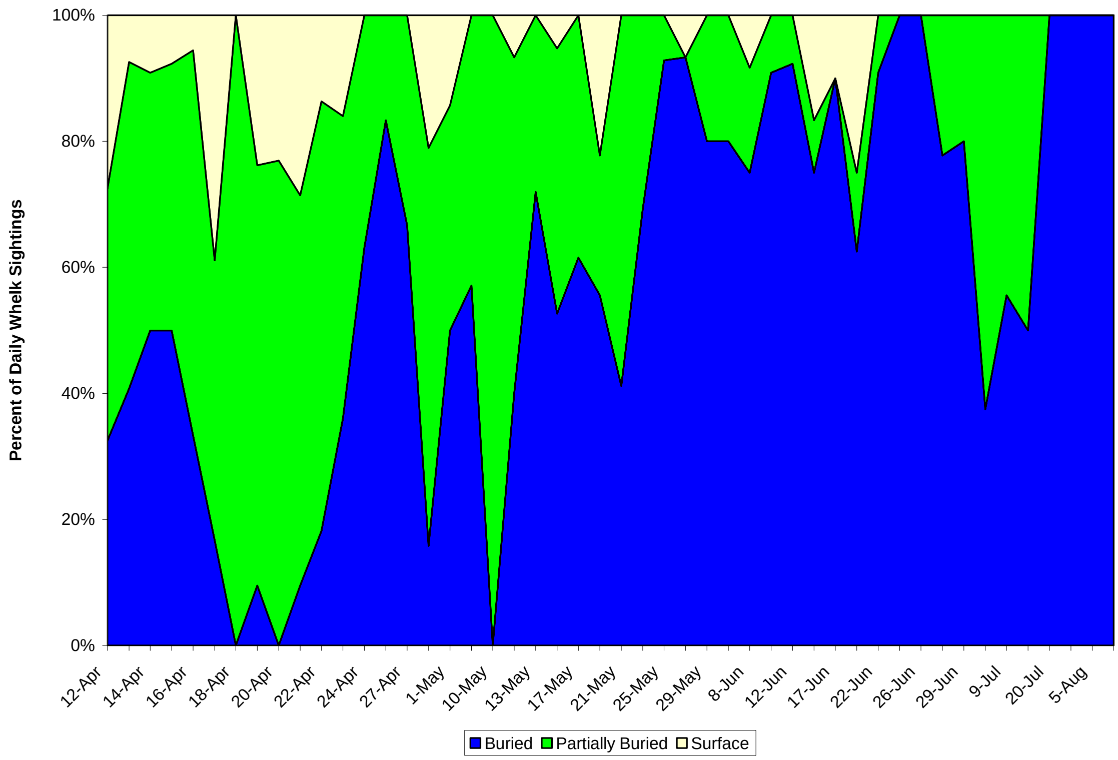

Figure 3.8. Percent of whelks found buried, partially buried or on the surface.

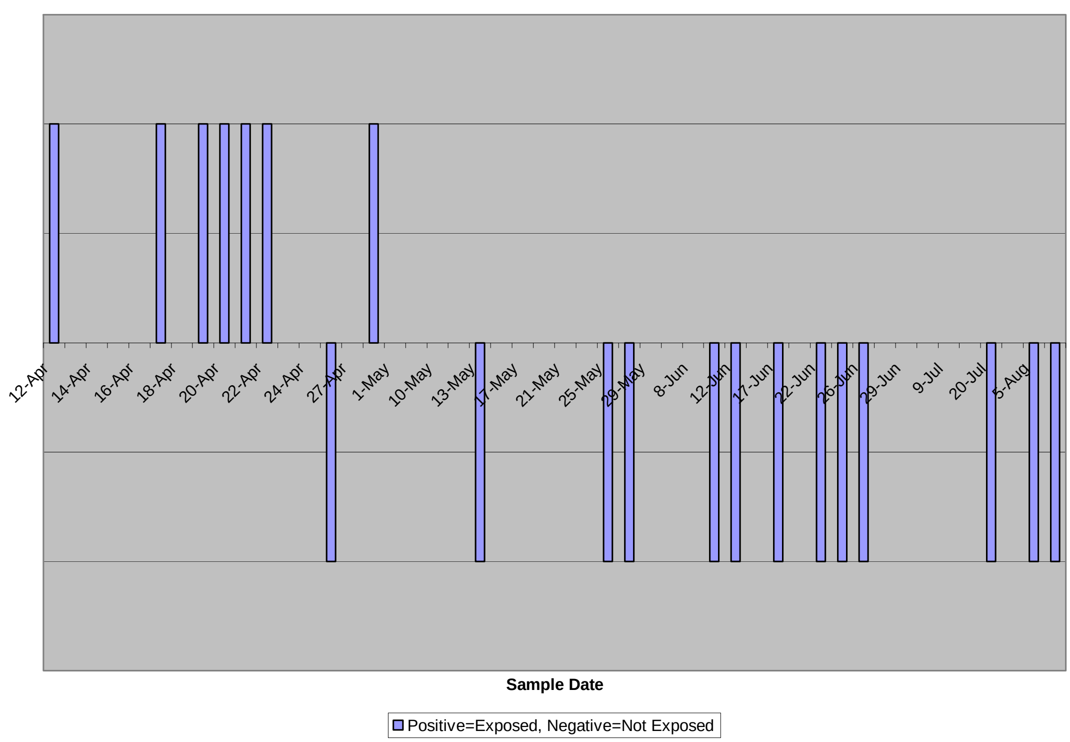

Figure 3.9. Chi squared significant differences in exposed whelks versus buried whelks.

Separate counts of all visible whelks (not just the whelks being tracked) on the right side oyster reef support the idea of active feeding while submerged during the summer months. Many knobbed whelks could be found on the oyster reefs immediately following a series of neap tides in which the reefs were submerged for several days. However, within one or two days following the submerged period, when the low tide levels began to fall, very few if any whelk were still visible on the reefs (Figure 3.10).

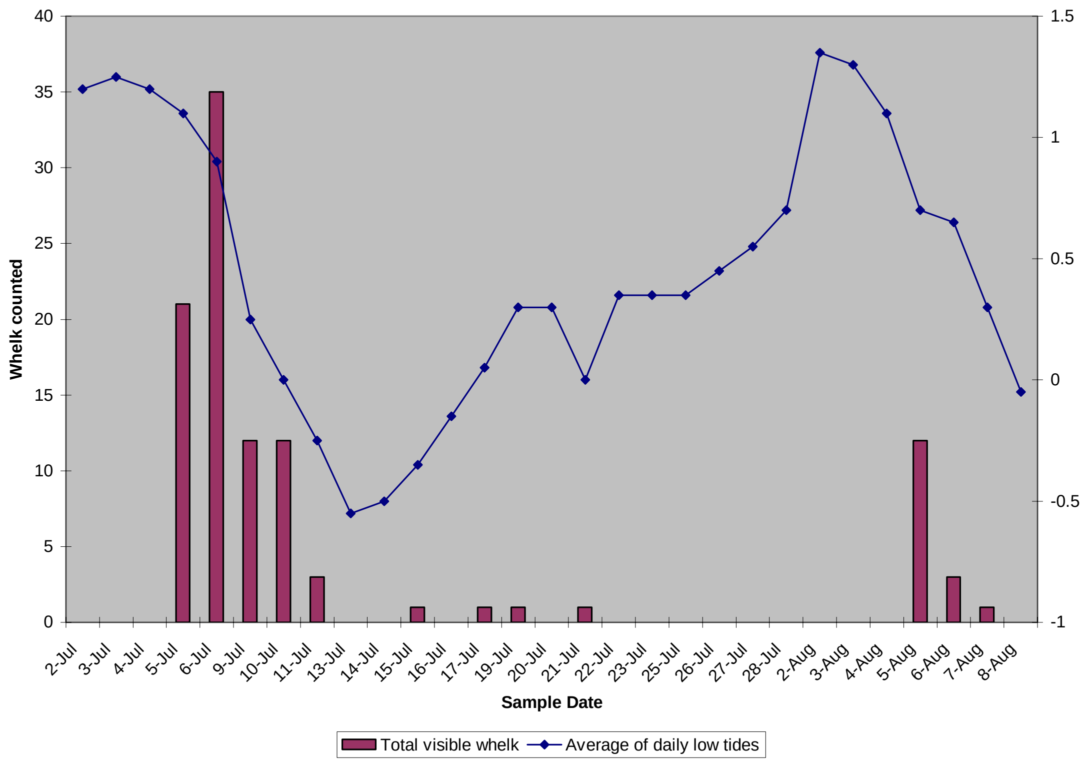

Figure 3.10. Counts of visible whelks on oyster reef in relation to low tide levels.

Discussion

After release, whelk randomly spread out away from the release point on the intertidal mud flat. However, by day 8 after release, whelks began concentrating on and near live oyster reefs (Figure 3.4). At this time, many naturally occurring whelks were observed on and around other oyster reefs in the area; however few whelks occurred away from the reefs in the intertidal muddy-sandy flats. The center reef and the right reef in the study inlet had higher live oyster densities than the left side oyster reef. From day 8 on, most whelks were located around the oyster reefs. This is consistent with previous reports of *B. carica* behavior. Knobbed whelks are known to feed heavily on bivalves (Colton 1908, Warren 1916, Magalhaes 1948, Carriker 1951, Menzel and Nichy 1958, Peterson 1982, Walker 1988) and occur in great numbers during the spring on oyster reefs in Georgia waters (Walker 1988).

Once whelks concentrated on and near the oyster reefs, future movement followed the contours of the oyster reefs. For movement pattern of 20 whelks that presumably left the tracking area by August; five whelks migrated around the contours of the left side and 15 around the right side of oyster reef when they were last located. Although only one whelk was located outside of the study inlet, it is presumed that the 20 whelks that were moving along the contours of the oyster reefs, continued to do so, as there is no evidence of them moving out onto the intertidal flat towards open water. A trapping study (Chapter 2) was started 300 meters directly out from the study inlet in Wassaw Sound on May 10, 2007. However, no whelks from this study were ever caught in the traps.

Knobbed whelk movement along the shore has been previously reported. Magalhaes (1948) reported movement of 1000 meters along a shore in North Carolina. Walker (1988) reported movements of 400 and 600 meters by knobbed whelks moving from one shellfish bed to another. The reefs beyond the study inlet were not as well organized as the ones inside the tracking area, so it is possible that a greater dispersion of the whelks occurred beyond the inlet. This may explain why attempts to locate whelk outside of the search inlet, along the shore as well as directly out from, proved mostly unsuccessful.

Of the 49 located whelks, only the movements of 3 whelks may have displayed evidence of direct movement across the intertidal flat or to subtidal areas (Figure 3.6). They were all males and all not located after one week of release.

Mortality of the tagged whelks was high. Nine of the 50 whelks released were confirmed dead throughout study. Several different possible sources of mortality were identified. One whelk was observed on an oyster reef upside down (aperture up) on an extremely hot and sunny day. The whelk was found deceased the next day presumably due to the exposure from the previous day. Another whelk was observed with numerous hermit crabs, *Clibanarius vittatus*, picking at the operculum before being found as an empty shell the following day. However, it is unclear whether the health of the whelk was somehow already compromised before the hermit crab attack. Finally, for five of the whelks, only shell fragments were located. Stone crabs (*Menippe mercenaria*) are common in the area and are known to prey upon small and medium size *B. carica* (Magalhaes 1948). Three of the five whelks could be considered rather large (162 mm, 171 mm, 176 mm total length); therefore it is possible that other predators may be responsible for some whelk predation as well.

The positions of the whelks varied from on the surface to completely buried (Figure 3.9). Whelks were divided into two groups: (1) those on the surface and partially exposed and (2) those completely buried (not exposed). Of the 680 recorded locations of whelks, in 322 instances the whelk was at least partly exposed and in 356 instances, the whelk was found completely buried. Although the positions seem relatively evenly split, the position of the whelks shifted from significantly more on the surface or partially buried (exposed) in April through the first week of May to significantly more buried (not exposed) for the rest of the study. This is presumably a response to increasing air and water temperatures (Figure 3.3) and solar radiant heating. Burying by whelks during the summer months has previously been reported by Walker et al. (2004). These results showed that as temperatures and solar radiant heating increases, whelks are found buried during the daytime low tide in summer months.

During May, untagged whelks became noticeably less abundant on the oyster reefs as well. Knobbed whelks in Georgia have been found to be abundant intertidally during spring and fall but are absent during summer and winter (Walker 1988). The extremes of temperature occur during summer and winter, whereas spring and fall have much more moderate temperatures. The tracked whelks were still quite abundant in the intertidal area, just not readily visible in daytime, during the summer months. The whelks continued to move around the inlet during May through August when significantly more were found buried. Therefore, it is likely the whelks are continuing to actively pursue prey or mates during high tide and then bury during low tide to escape environmental extremes.

Presumably the continuous submersion of the oyster reef provided an opportunity for the whelk to feed on the live oysters while not being exposed to the intense summer heat. When the tide level began to drop and expose the reef, the whelk moved off the reef into the lower, muddier areas to escape heat exposure by burying during low tide. Metal tagged whelks were located below the oyster reef buried on the intertidal flat during low tide levels and periods when few whelks naturally occur on the oyster reef.

Individual daily whelk movement ranged from no movement to a high of 52.9m d^{-1}. Assuming movement only when submerged (~18 hr), a speed of 52.9m d^{-1} is equal to 0.82 mm s^{-1}, which is close to previously reported laboratory speeds of 0.83 mm s^{-1} to 1.67 mm s^{-1} (Magalhaes 1948). The actual speed may have even been greater as our calculation assumes the whelk proceeded in a straight line. In field observations, Magalhaes (1948) reported movements of 15 m d^{-1} to 40 m d^{-1} with an average movement of 18 m d^{-1}. Walker et al. (2004) reported speeds of 2.5 m d^{-1}.

Although individual minimum daily movement rates were not significantly different for most of the whelks, movement rates between males and females as groups were significantly different (ANOVA $p<0.0001$). Females as a group had a calculated mean minimum daily movement of 2.57 m d^{-1} which was almost a meter greater than the males mean of 1.61 m d^{-1}. The significance was not due to an extreme skewing of the mean by the female with only one calculation mentioned previously. Exclusion of that female still resulted in a significant difference between male and female movement. It is unlikely that this is simply a difference in body size as well. No correlation was found between the movements of the whelks and their body lengths. *Busycon spp*. generally crawl by means of cilia (Gainey 1976). Of the many types of locomotion by gastropods, ciliary movers show the least correlation between size and speed (Linsley 1978). However, it is possible that the greater movement is a result of the greater energy demand by female whelks in the production of eggs and egg cases. Females of the commercial species *Buccinum undatum*, use 6 to 16 times more energy for reproduction than males of the same species (Martel et al. 1986, Kideys et al. 1993). Although no females in this study were observed laying eggs, females have been readily observed on lower intertidal mud flats laying egg cases in the spring months in Georgia (Power et al. 2002).

By completion of the tracking in August, only nine of the 50 released whelks could still be found inhabiting the inlet. In the last month of tracking, several of the pieces of aluminum flashing that were used to locate the whelk by metal detector were found. It is possible that more of the tagged whelks were still in the inlet but not located due to the loss of the attached metal. Additionally, Walker et al. (2004) reported knobbed whelks buried from 1 to 14.4 cm deep in intertidal areas. It was determined that the pieces of metal flashing used in this study could only be detected up to a depth of 8 cm. Whelks burying to the depths reported by Walker et al. (2004) would most likely go undetected by the metal detector being used to locate the whelks. This may have also contributed the assumption that many of the whelks had left the study inlet.

This study shows that whelks on the intertidal tend to concentrate on or near oyster reefs from April to August. The movement of most of the whelks was along the contours of oyster reefs. This study also shows that although whelks may be visually more abundant during early spring and absent during the hotter late spring and summer months, they remain in the area. They bury during low tide, presumably to avoid exposure to the higher temperatures, yet remain quite active during high tide.

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Appendix

Table 3.1. Supplemental data on the tagged *Busycon carica* used for tracking.

Tag	Length (mm)	Sex	Number of sightings	Number of days tracked	Average movement (m d^{-1})
A002	174	F	13	40	4.84
A004	173	F	17	46	2.57
A043	184	F	32	86	1.73
A049	164	F	7	14	7.6
A057	106	M	4	8	12.57
A069	174	F	20	118	1.29
A074	105	M	10	36	1.64
A083	116	M	13	79	1.40
A094	160	F	15	65	2.75
A099	134	F	22	89	1.46
A107	90	M	3	5	12.98
A128	151	F	23	117	2.38
A133	95	M	6	30	2.46
A145	165	F	21	86	2.82
A166	118	M	16	69	1.58
A207	78	M	8	100	1.69
A352	171	F	18	42	2.46
A366	160	F	20	69	3.12
A376	121	F	11	72	2.03
A378	162	F	11	20	6.10
A383	134	F	6	32	2.73
A394	156	F	42	117	1.85
A410	90	M	0	N.A.	N.A.
A429	189	F	19	78	3.38
A430	166	F	2	3	13.84
A447	222	F	26	76	3.05

A451	176	F	21	72	2.47
A453	140	F	9	32	2.57
A459	130	M	23	65	1.49
A482	134	F	6	32	5.76
A485	161	F	1	1	46.50
A486	140	F	27	119	2.06
A489	103	M	19	89	1.64
A490	105	M	4	4	4.11
A535	110	M	9	118	0.98
A692	88	M	20	89	1.75
A693	88	M	7	39	3.02
A697	90	M	9	79	1.28
A701	84	M	11	99	1.51
A715	113	M	11	89	1.54
A733	107	M	3	6	12.45
A754	83	M	5	20	2.45
A759	87	M	5	42	1.27
A774	146	F	9	16	6.05
A816	89	M	26	89	1.29
A823	87	M	23	116	0.87
A825	89	M	20	116	0.66
A893	93	M	4	76	1.22
A916	81	M	2	6	13.07
A917	144	F	20	118	2.34

CHAPTER 4

CONCLUSIONS

The two studies provide greater insight into the life histories of whelks on the Georgia coast. The trapping study provides insight into alternative means of commercially harvesting whelks after a failure in the trawl fishery. It establishes a relatively simple way of modifying traps currently used in the blue crab fishery to increase total yield for the fisherman. The tracking study provides a greater understanding of knobbed whelk life histories. Before the study, it was unclear whether knobbed whelks moved to subtidal areas or just buried in the intertidal sediment during the extreme temperatures that coastal Georgia receives during the summer. It was also unclear where males could be found before or after mating as females often greatly outnumber males on intertidal areas.

Whelk Trapping Study (Chapter 2)

A total of 734 whelks [47.7% channeled (*B. canalicalatus*), 34.7% knobbed (*B. carica*), 17.6% pear (*B. spiratus*)] were caught at both sites. Traps with smooth plastic surfaces caught more whelks than traps without at each location. The plastic pyramid trap caught more whelks (40%) than any other trap. The standard crab trap and modified crab trap averaged higher weight catches than the other traps for all species. The modified crab trap caught the second most whelks (188) behind the plastic pyramid trap

(286), and had high average catch weights therefore may provide the best opportunity for a viable commercial whelk harvest. Significantly more males were caught in the open sound location and more females in the tidal creek location. Significantly heavier ($p<0.0001$) channeled whelks were caught in the tidal creek and heavier ($p<0.0001$) knobbed whelks were caught in the open sound. No pear whelks were caught in the tidal creek.

Movement and Behavior Study (Chapter 3)

After the initial release, the whelks (*Busycon carica*) began to randomly spread out across the intertial mud flat away from the release point. By day 8, whelks had concentrated on and near live oyster reefs. The average individual minimum daily movement rate was significantly different (ANOVA $p<0.0001$) for males (mean 1.61 m d^{-1}) and females (mean 2.57 m d^{-1}). In April, chi-squared tests showed significantly more whelks were observed on the surface or partially exposed; but in May through August significantly more whelks were found buried, presumably to escape higher daytime temperatures. During the hotter months, whelks could be found in greater numbers exposed during the low tides following neap tides that did not expose the intertidal area. At completion of tracking, 1 whelk had never been located, 9 were still in the tracking area, 9 were confirmed dead, 24 had been at edge of the search area during last location and presumably moved out of area, and 7 were lost in the search area presumably due to lost metal tags. This study shows that knobbed whelks remain in the intertidal areas during the normal low visual abundance periods of the summer months. This study also shows that the whelks remain active during these months by moving during high tide and then burying before the tide recedes.