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A 50 Year Accomplishment in Marine Science: A History of the Journal Published by the Gulf Coast Research Laboratory

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A 50 YEAR ACCOMPLISHMENT IN MARINE SCIENCE: A HISTORY OF THE JOURNAL PUBLISHED BY THE GULF COAST RESEARCH LABORATORY

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Abstract: The Gulf Coast Research Laboratory (GCRL) has a 50 year history of annual publication of the peer-reviewed journal *Gulf and Caribbean Research* (GCR, 2000-present; formerly *Gulf Research Reports* (GRR) from 1961—1999). Other extant journals serving the region during this time include *Contributions in Marine Science* (since 1945), *Proceedings of the Gulf and Caribbean Fisheries Institute* (since 1948), *Bulletin of Marine Science* (since 1951), *Revista de Biología Tropical* (since 1953), and *Caribbean Journal of Science* (since 1961). In the early years of the GCR publication, papers were primarily concerned with research in Mississippi and the northern Gulf of Mexico (GOM), and the majority of authors were from USM/GCRL or the GOM region. However, in the past 15 years, studies from Mexico and the Caribbean have dramatically increased, with a concurrent increase in the geographical diversity of authors. Overall, surveys and inventories, taxonomy, and life history studies have been most common, and taxa have been dominated by fish and crustaceans. Offshore, benthic and marsh habitats have been the most commonly studied during GCR's 50 year history. In general, publications during the last 15 years are more similar to each other (≥ 65% similarity based on CLUSTER analysis and MDS ordinations) than to earlier publications for geography, taxon, habitat and subject areas. The journal is well cited in peer-reviewed literature, with 72% of the papers published in GRR and 65% of those published in GCR cited at least once. GCR provides an important outlet for peer-reviewed publications from the GOM and Caribbean region.

Key Words: Citation history, taxa, habitats, Gulf of Mexico, Caribbean

Introduction

In the early 1960s, Dr. Gordon Gunter, then the Director of Gulf Coast Research Laboratory (GCRL), almost singlehandedly developed the concept of *Gulf Research Reports* (GRR) as a mechanism ". . . devoted primarily to publication of the data of the marine sciences, chiefly of the Gulf of Mexico and adjacent waters." The first issue appeared in April 1961 with Dr. Gunter as Editor-in-Chief, and since that time GRR has produced 51 issues covering over 453 reports (through the 2010 issue), including four special issues on the resources and processes of the Gulf of Mexico (GOM) and adjacent waters.

The journal has had 6 Editors-in-Chief during the course of publication (Figure 1), with the Director of the GCRL serving as Editor-in-Chief of GRR until the 1997 issue (volume 9(4)). The editorship of GRR was passed on to the late Dr. Harold D. Howse from Dr. Gunter beginning with the 1975 issue. At that time the journal was reformatted to a larger page size (Figure 2) and a nominal page charge

Figure 1. *Journal Editors-in-Chief. A. Gordon Gunter (1961-1974). B. Harold D. Howse (1975-1992). C. Thomas D. McIlwain (1994-1995). D. Robert T. van Aller (1996). E. Richard W. Heard (2002). F. Mark S. Peterson (1997-2001; 2003-present).*

Figure 2. *Various covers of the journal illustrating changes made over the course of publication. A. 1961-1972; B. 1973-1974; C. 1975-1997; D. 1998-1999; E. 2000-2007; F. 2008-present.*

was, for the first time, assessed to help defray the cost of publication. The first "Guide to Authors" appeared in that issue and manuscripts had to be found acceptable by at least two referees (Howse 1975). Dr. Howse remained Editor-in-Chief of GRR through 1992 (volume 8(4)), at which time Dr. Thomas D. McIlwain became Editor and guided the 1994 and 1995 issues to print. Interim GCRL Director, Dr. Robert T. van Aller, served as Editor of GRR for the 1996 issue. In 1997, the duties of GCRL Director and Editor

were separated, and Dr. Mark S. Peterson became Editor-in-Chief with the 1997 through 2001 issue and has continued to serve in that capacity from the 2003 issue through the present time. Dr. Richard W. Heard was Editor-in-Chief for the 2002 issue (Volume 14).

As the number of submissions to the journal increased, an editorial staff became a necessity to help make the journal a better publication. From 1980 until 1996, Ms. Susan Griggs acted as Assistant or Managing Editor, Ms. Linda Skupien was Managing Editor from 1998–2000, and later Ms. S. Dawne Hard was Assistant (1998–2000) and then Managing Editor (2001–2007), each providing guidance with their expert editorial, type-setting, and managerial skills. In addition to the editorial staff, Catherine M. Campbell (1975–1985), Mereau Tacon (1989), Gina Dieterick (1991–1994), Vicki Crane (1991–1998), Dale Fremin (1997–2000), and the Gunter Library staff (Joyce M. Shaw (2002–2008) and Marjorie G. Williams (2002–2007)) assisted with journal production activities. A new editorial team came on board in 2007, comprised of Nancy Brown-Peterson (Assistant Editor, 2007–2010, Co-Editor, 2011), Diana Reid (Graphic Designer, 2007–present), Angelia Bone (Editorial Assistant, 2007–2009), and Pamela Moeller (Editorial Assistant, 2009–present). This team has allowed us to produce an updated and more professional journal and these changes, plus a more-stylistic cover (Figure 2) and layout modifications, have been received well by the authors and readership of GCR.

Changes in GRR procedures were instituted in 1997 and continue to be modified and refined today. An Advisory Board, chaired by the Editor-in-Chief, was appointed in 1997, providing vital information, guidance and policy for the production of GRR. All changes and modifications to GRR are discussed, reviewed and voted on by the Advisory Board. At this time, a set of Associate Editors was also appointed, comprising national and international experts, to bring disciplinary depth and international perspective to GRR. All Associate Editors have a two year appointment, but a number serve longer with mutual approval between the Associate Editor and the Editor-in-Chief. Some have served as long as six years. This major change in GRR policy has been an important and fruitful one.

The Advisory Board has approved a series of operational and cosmetic changes to the journal in the past 13 years. In 1997, we removed the page charges for published manuscripts and initiated a nominal subscription fee, but in 2009 we went back to a page charge for manuscripts longer than 10 printed pages as costs continued to increase. The 1997 issue also included a complete revision of the "Guide to Authors" and "Scope" of GRR, and a change in the volume numbering sequence of GRR issues. The Advisory Board modified the cover again in the 1998 issue (volume 10) by including the new Institute of Marine Sciences logo in lieu

of the GCRL logo (1998–1999 and supplement 1 that year; Figure 2). These modifications were made to help our readership recognize the changes within the GCRL, the publisher of GRR (Grimes 1998).

During 1998, the Advisory Board, in consultation with GCRL Director Dr. Jay Grimes, began discussions about major changes in GRR. These changes would result in the ultimate goal of making GRR a ". . . widely recognized source of scientific information that underpins the understanding, planning, and management of GOM and Caribbean natural resources and processes" (Grimes 1998). Our goal was thus to reformulate and repackage the original vision of GRR. At the 1998 Advisory Board meeting, we voted to update the "Guide to Authors" and the "Scope" and to remove a published submission deadline such that more manuscripts might be submitted to the journal, with the ultimate vision of publishing two issues annually. Finally, we voted to change the name of the journal from *Gulf Research Reports* to *Gulf and Caribbean Research* (GCR) effective in Volume 12 published in the year 2000 (Figure 2). This name change more accurately reflects the scope of the papers published in the journal and better reflects our mission and audience. The Advisory Board felt these changes supported and extended the original vision of the journal founder, Dr. Gordon Gunter.

In an effort to provide visibility for GOM scientific societies, the journal has periodically published abstracts/ symposium sessions from their meetings. Abstracts from the annual meeting of the Gulf Estuarine Research Society (GERS) were published in GRR in 1998, 1999 and 2001.

Two special issues (Marine Protected Areas and Large Pelagic Fishes in the Caribbean Sea and Gulf of Mexico: Current Status and Integrated Management) that were based on special symposia at the Gulf and Caribbean Fisheries Institute (GCFI) meetings were published in 2003 and 2007. Additionally, two special sections, published in 2004 and 2005, included papers from the southern GOM based on undergraduate research theses at the Iztacala campus of the Universidad Nacional Autónoma de México. These efforts represented the first scientific publication for many young Mexican scientists.

The March 2011 issue will be the 50th year of publication for GRR/GCR. In acknowledgement of this golden anniversary, the Advisory Board decided to review the scope and direction of the journal over the course of its existence. The purpose of this article is to provide a summary of the authors, topics, and diversity of this well established regional marine science journal, and to illustrate that despite growth and numerous changes, GCR remains true to its initial mission of disseminating information pertinent to the GOM and adjacent waters.

Methods

In order to examine journal content and thus trends over time, we pooled all papers within five year periods of time from 1961–2010 ($n = 10$ date sets). We then developed six topics to examine over these date sets: large-scale author affiliation (2 locations - USM/GCRL vs. other intuitions), finer-scale geographic distribution of authors ($n = 8$ locations), geographic distribution of study sites ($n = 6$), subject areas ($n = 11$ categories), taxon representation ($n = 9$), and habitat

TABLE 1. *Summary of important metrics for each set of five years of the journal. 1-λ' represents a form of Simpson Index (Krebs 1989; Clarke and Gorley 2006) and is interpreted as low values equal low diversity and high values equal high diversity. Large format issues started in 1975. The values in parentheses after the data sets correspond to the MDS plots in the figures.*

| Date set	# issues	#total papers	#total pages	mean# pages/ article	Author geographic distribution 1-λ'	Study site geographic distribution 1-λ'	Subject 1-λ'	Taxon 1-λ'	Habitat 1-λ'
61-65(1)	7	10	470	47.0	0.407	0.618	0.499	0.727	0.750
66-70(2)	4	17	529	31.17	0.438	0.489	0.811	0.762	0.684
71-75(3)	5	34	703	20.7	0.247	0.555	0.824	0.870	0.814
76-80(4)	5	61	377	6.2	0.135	0.622	0.853	0.876	0.841
81-85(5) & supplement	6	73	484	6.6	0.406	0.661	0.857	0.836	0.795
86-90(6)	1	12	145	12.1	0.280	0.519	0.491	0.673	0.617
91-95(7)	4	43	334	7.8	0.467	0.693	0.807	0.745	0.770
96-00(8) & supplement	6	47	489	10.4	0.600	0.761	0.843	0.798	0.621
01-05(9) & special issue	6	79	687	8.7	0.783	0.767	0.848	0.723	0.789
06-10(10) & special issue	7	64	475	7.4	0.662	0.682	0.860	0.661	0.730

type representation (*n* = 9). Detailed information regarding contents of the categories within the topics can be found in Appendix 1. We also calculated the number of papers, the total number of pages, and the mean number of pages per paper by date set. Published information not incorporated into these analyses included annual reports of GCRL activities, GERS abstracts, editorials, introductions or summaries to special sections or symposia, and obituaries. We examined what other journal papers cite our journal using *ISI Web of Science, Publish or Perish* ™ and *Google Scholar* software (Harzing 2010), what were the most cited papers, and who are the most cited authors. We also determined the longevity of similar regional marine science serial publications and provide our readership information on what abstracting or indexing services list our journal.

Cluster analysis based on the hierarchical agglomerative method with the group-average linkage and non-metric multi-dimensional scaling (MDS) procedures were used to compare the six topics (based on square root transformation of categories within each topic separately by the 10 date sets) with the Bray–Curtis similarity coefficient. Both analyses

were computed using PRIMER (version 6.1.6; PRIMER-E Ltd, Plymouth, UK, Clarke and Gorley 2006); these values range from 0 to 100 % with 0 % being no similarity and 100 % being identical (Clarke 1993). Both analyses attempt to create groupings of topics based on the date sets through a generated similarity matrix. We also conducted a SIMPROF test on the cluster analysis to search for meaningful structure within the clusters. Finally, we superimposed groups based on SIMPROF results, or if no structure was identified, by visual groupings in the cluster dendrogram at similarity level, visually defining groups onto the ordination to search for mutual consistency between techniques.

We also calculated a form of Simpsons Diversity Index (1-λ'; Clarke and Gorley 2006) for these topics by date sets. This index is interpreted as low values equal low diversity and high values equal high diversity. This index is one of the least influenced by differences in sample size (Magurran 1988; Krebs 1989), and represents changes in patterns (i.e., diversity of topics over date sets).

Finally, we compared our results to similar patterns from the 60 year history of the *Proceedings of the Gulf and Carib-*
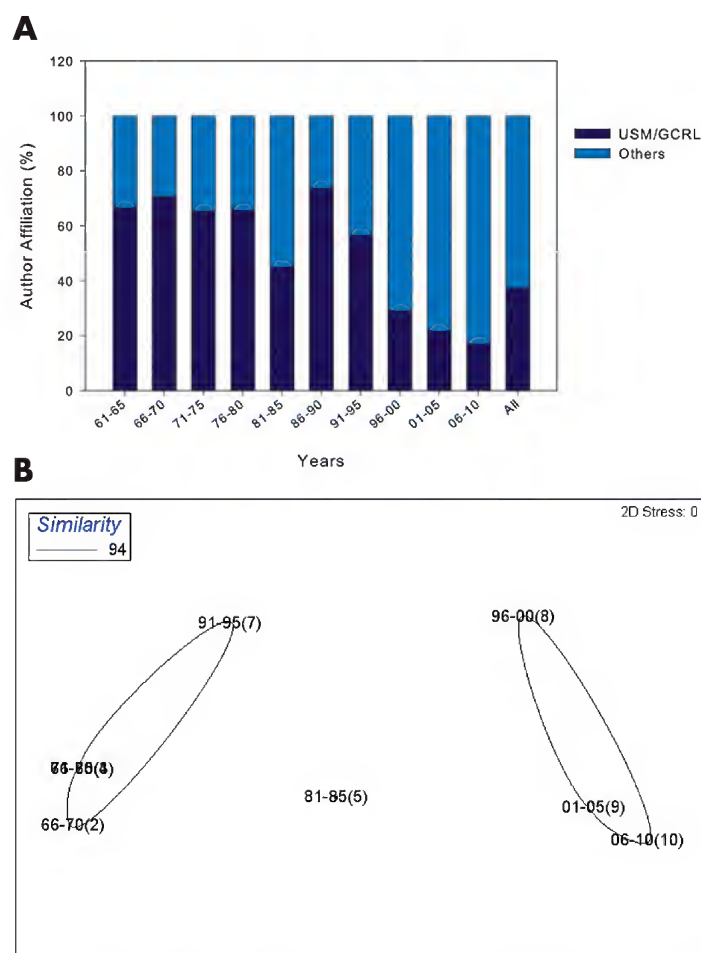
Figure 3. *Summary of (A) large-scale author affiliation (USM/ GCRL) vs other affiliated authors who published in the journal by date set and (B) MDS plot of square-root transformed data in panel A.*
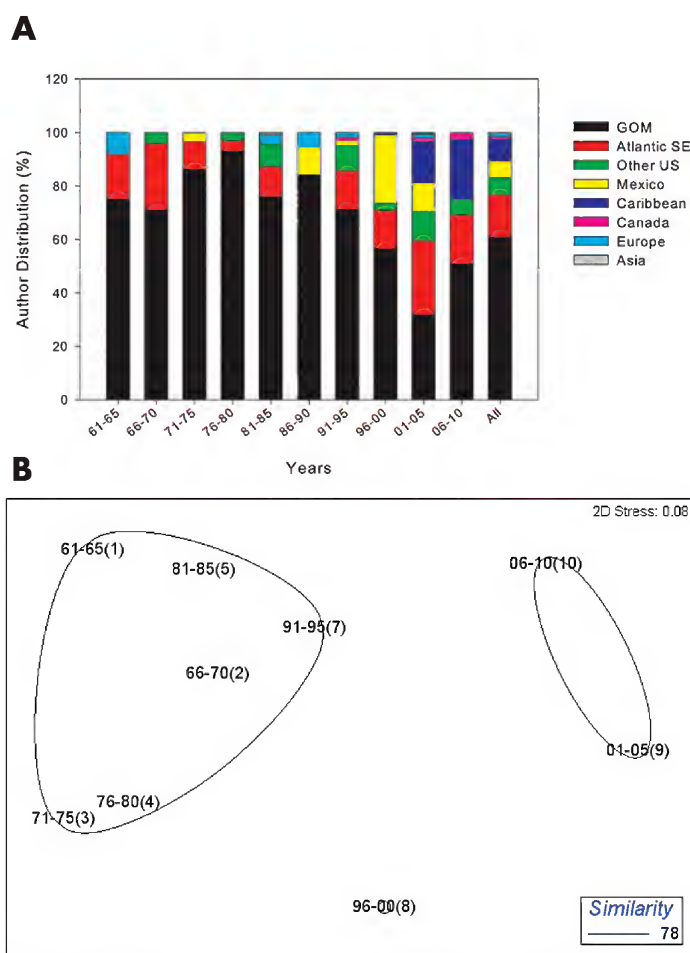
Figure 4. *Summary of (A) fine-scale distribution of the author's affiliation who published in the journal by date set and (B) MDS plot of square-root transformed data in panel A.*

TABLE 2. *Summary of publication duration of regional journals that publish or are focused on marine science research in the Gulf of Mexico and Caribbean areas. Journals in bold are still published. * = not peer-reviewed. Superscripts of the same letter indicate different titles of the same journal.*

Journal	Initial year	Final year
Alabama Marine Resources Bulletin	1969	1982
Bulletin of Marine Science of the Gulf and Caribbean[a]	1951	1964
Bulletin of Marine Science[a]	1965	
University of Texas, Publication of the Institute of Marine Science[b]	1945	1966
Contributions in Marine Science[b]	1967	§
Caribbean Journal of Science	1961	
*Florida Board of Conservation, Marine Research Laboratory Professional Papers**	1960	1967
*Florida Department of Natural Resources, Marine Research Laboratory Professional Papers**	1969	1973
*Florida Department of Natural Resources, Florida Marine Research Publications**	1973	1998
Gulf Research Reports[c]	1961	1999
Gulf and Caribbean Research[c]	2000	
Journal of Marine Science[d]	1969	1973
Northeast Gulf Science[d]	1977	1996
Gulf of Mexico Science[d]	1997	
Proceedings of the Gulf and Caribbean Fisheries Institute*	1948	
*Proceedings of the Annual Conference SE Association of Game and Fish Commissioners**[e]	1956	1975
Proceedings of the Annual Conference SE Association of Fish & Wildlife Agencies*[e]	1976	
Revista de Biología Tropical	1953	
Tulane Studies in Zoology[f]	1953	1968
Tulane Studies in Zoology and Botany[f]	1968	2002

§ indicates irregular, non-annual publication since 1999.

bean Fisheries Institute. Percentages of author affiliation, subject matter and taxon in categories similar to those for the GRR/GCR analysis were calculated from data presented in Posada and Franks (2008).

Results and Discussion

Our journal was established in 1961 and has been published once yearly (some years had two issues and some had additional special issues, sections or supplements) except during the years 1986 thru 1988 and 1990 when budget issues prohibited publication. Overall, the journal has published a total of 51 issues, 453 total articles, 4,693 total pages, and the mean number of pages per article ranged from 6.2 to 47.0 (Table 1). The mean number of pages per article decreased starting in 1976 when page size of our journal increased (Table 1).

Many of the papers in early volumes focused on local and regional issues, processes and problems. Through the years, however, papers appeared from authors outside the local and regional areas which focused on organisms and/or processes relevant to the GOM and adjacent waters. Papers have been published from scientists in Denmark, Germany, Sweden, Canada, Japan, Mexico, and the Caribbean Sea nations, giving a more international flavor to the journal.

Our journal is one of the longest published regional marine science journals compared to other serial publica-

tions in the region that publish marine science disciplines (Table 2). The only other regional journals in continuous publication longer than GRR/GCR are *Bulletin of Marine Science*, *Proceedings of the Gulf and Caribbean Fisheries Institute*, *Caribbean Journal of Science*, and *Revista de Biología Tropical* (Table 2).

Our journal is also abstracted and indexed in seven services:

- ASFA: Aquatic Sciences and Fisheries Abstracts
- Biological Abstracts
- British Library Direct
- ProQuest CSA Illumina
- Oceanic Abstracts
- Zoological Record
- REFERATIVNYI ZHURNAL (All-Russian Institute of Scientific and Technical Information Journal (www.viniti.ru)).

This makes articles published in GCR readily available to the scientific and management communities worldwide.

Analysis of published articles

After the initial processing of data and statistical procedures, it was clear that results from the 1986-1990 date set skewed all analyses because there was only one issue published in those five years (Table 1). Thus, although we plotted data from this date set in the histograms and included

these data in calculated Simpson's diversity estimates, we did not include those data in the cluster analysis or the MDS ordinations. Also, we did not calculate Simpson's diversity for the author affiliation data (Table 1) because there were only 2 categories. Finally, the SIMPROF analysis on the clusters indicated only the author affiliation (Figure 3), subject area (Figure 6), and the taxon analyses (Figure 7) had significant structure with all clusters, and for those analyses we used those groups to superimpose onto the MDS plots based on similarity values. However, for the remaining data sets that did not show significant structure, we superimposed groups based on the actual breaks in the cluster analysis to aid in interpreting the patterns in the MDS plots.

During the first 20 years of publication, authorship was dominated by USM/ GCRL personnel; however, during the last 15 years, the majority of authors have not been from USM/GCRL (Figure 3A). Overall, 37% of the articles published in GRR/GCR have been by authored or co-authored by personnel affiliated with USM/GCRL. SIMPROF analysis indicated there were three significant groups within the structure of the cluster and MDS analyses of author affiliation (Figure 3B). These groupings show the clear trend of a

lower percentage of USM/GCRL authors in recent years.

For the geographic distribution of authors data set, there was a general pattern of domination by authors from the GOM during 1961–1995 (Figure 4A) and highly variable diversity (Table 1). However, since 1996 there has been an increased percentage of authors from Mexico and the Caribbean region, as well as stable, high Simpson's diversity (Figure 4A, Table 1). This difference is reflected in three distinct groups displayed on the MDS plot (Figure 4B) at the 78% similarity level.

The geographic areas reflected in the published studies also show profound variation over time. During the first 15 years, most studies were conducted in Mississippi with a relatively small percentage of studies from other GOM areas, the Caribbean and Mexico (Figure 5A), and these years also showed the lowest diversity indices (Table 1). Beginning in 1976, the percentage of Mississippi studies declined, the percentage of GOM studies increased, and studies from the southeastern Atlantic first appeared (Figure 5A). Diversity was similar among issues from 1976–1995 (Table 1) and these years cluster together in the MDS plot (Figure 5B). During the last 15 years, ≤50% of the papers published have
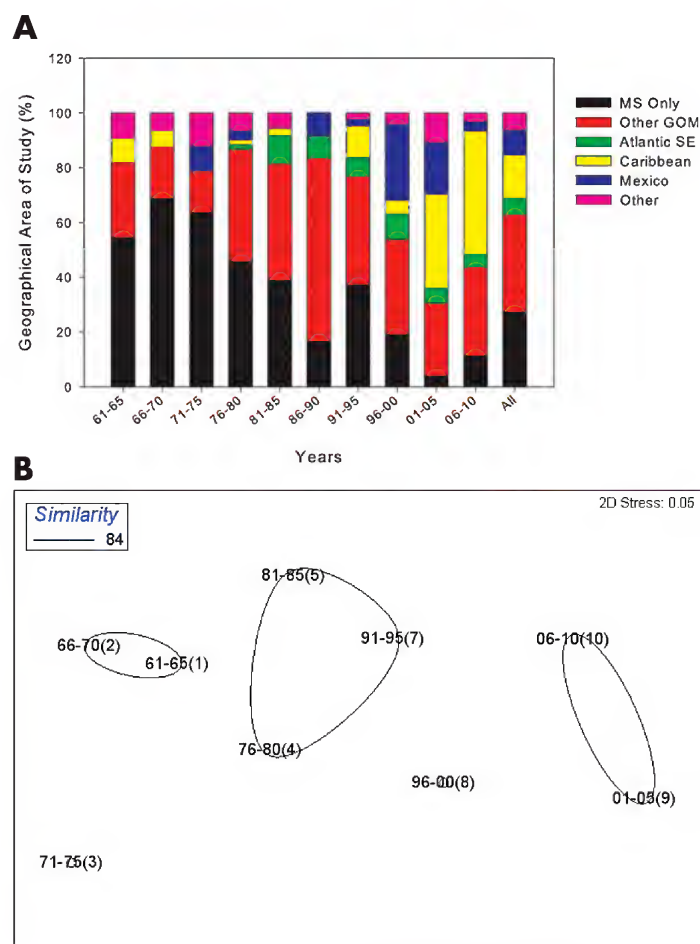
Figure 5. *Summary of the (A) geographic area of study sites published in the journal by date set and (B) MDS plot of square-root transformed data in panel A.*
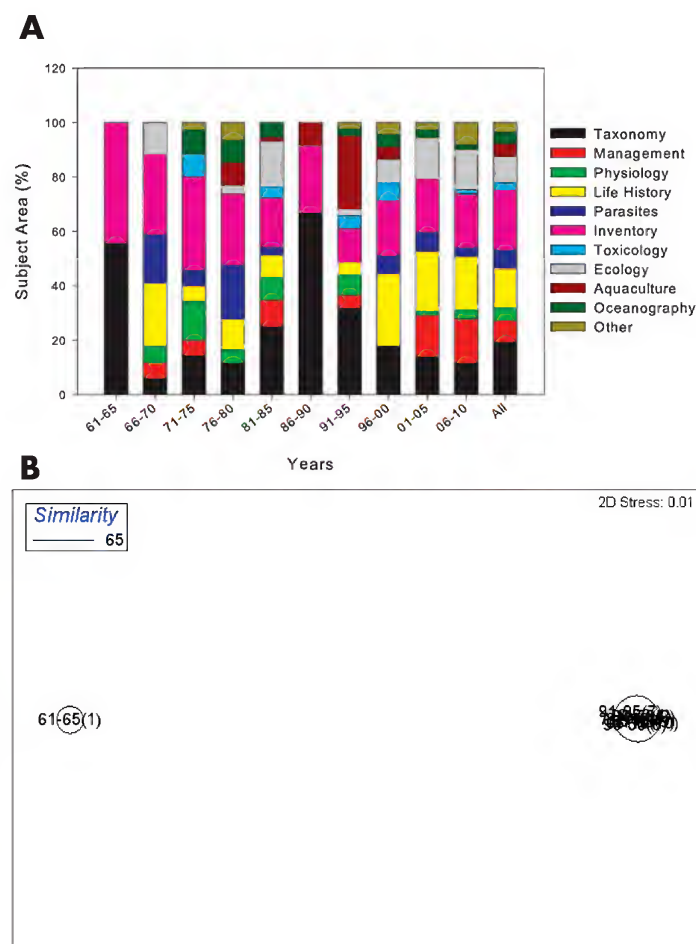
Figure 6. *Summary of (A) subject areas published in the journal by date set and (B) MDS plot of square-root transformed data in panel A.*

TABLE 3. *Summary of external citations using articles from Gulf Research Reports and Gulf and Caribbean Research.*

Gulf Research Reports (1965-2010)	ISI Web of Science™ articles	Times cited	Total number of citations	Publish or Perish™ & Google Scholar articles	Total number of citations
	5	40+	269	3	209
	12	20-39	353	12	332
	44	10-19	570	28	374
	159	1-9	551	112	463
Totals	220		1,743	155	1,378
Gulf and Caribbean Research (2000-2010)					
	7	10+	144	8	212
	9	5-9	58	18	103
	61	1-4	121	72	115
Totals	77		323	98	430

been from the GOM region (including Mississippi) and the contribution of studies from Mexico and the Caribbean has been noticeably higher. The most recent date sets show the highest Simpson's diversity index (Table 1) and are separated from the other years on the MDS plots (Figure 5B).

With the exception of 1961–1965 and 1986–1990, there was a high diversity in subject area for all date sets (Table 1), resulting in just 2 significantly separated groups in the MDS plots (Figure 6B). The only subject areas occurring in all date sets were inventory/surveys and taxonomy, and these two categories, along with life history studies, were the most common subject areas overall (Figure 6A). Some subjects were only found during certain periods of the journal's publication history, such as aquaculture (1976–2000). Papers on parasites were not published from 1986–1995, but were present in all other years after 1965 and oceanography papers were published in all years after 1970 with the exception of 1986–1990.

There is a high diversity in the taxon data set for all years (Table 1), yet SIMPROF clearly showed significant structure in the clusters and MDS plot, with the 1961–1965 data set separated from all other data sets (Figure 7B). This separation could be due to the high percentage of papers in the multi-taxa category in 1961–1965 (Figure 7A) because of the numerous inventories conducted during those years. Overall, fish was the most common taxon (28.7%), followed closely by Crustacea (27.4%, Figure 7A). Microorganisms and Mollusca were more commonly represented prior to 1986, and plants occurred in only 4 of the 10 date sets (Figure 7A). All 9 taxon categories were only represented from 1971–1985 and again in 2006–2010, although there was a much more even representation among the taxon categories in the 1970's and early 1980's (Figure 7B).

For the habitat data sets, the offshore and benthic categories dominate the overall patterns, but there was a consistent but lower percentage of marsh habitat as well; these are the only 3 habitat categories that were represented in all date sets (Figure 8A). The MDS plots show that the first 25 years grouped together, likely due to a similar distribution and number of habitat categories (Figure 8A,B). The data set from 1991–95 grouped with the 2006–10 data set, most likely due to a similar percentage of lab studies in those years (Figure 8A,B). Data sets from 1996–2005 each had 6 habitat categories and were grouped together (Figure 8A,B).

Recently, the Gulf and Caribbean Fisheries Institute celebrated their 60th year, and analyzed trends in papers presented at annual meetings from 1948–2004 and subsequently published in the *Proceedings* (Posada and Franks 2008). Although the papers published in the *Proceedings* reflect the identified themes established for each annual meeting, there are some similarities among publication trends with GRR/GCR when looking at geographical distribution of authors, subject areas, and taxa.

Author data from the *Proceedings* are based on the 20 most published authors for each 10 year period, and thus are not directly comparable to author data from GCR. However, from 1948–1977 the majority of articles were authored by scientists from the GOM, and the second largest percentage of authors were from the southeastern United States (Posada and Franks 2008), similar to trends seen in GRR/GCR. Interestingly, from 1978 until 2004, authors from Caribbean countries represent the highest percentage in the *Proceedings*, whereas Caribbean authors have only made a significant contribution to GCR since 2001 (Figure 4A). Finally, the recent prevalence of authors from Mexico is evident in both journals; from 1998–2004, 25% of the articles in the *Proceedings*
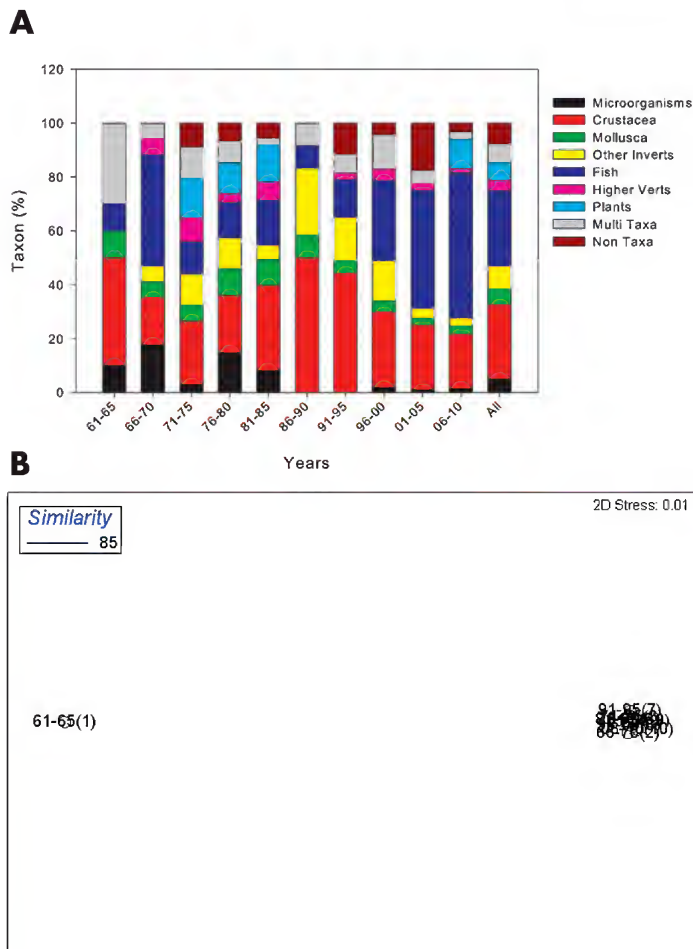
Figure 7. *Summary of (A) taxon representation published in the journal by date set and (B) MDS plot of square-root transformed data in panel A.*
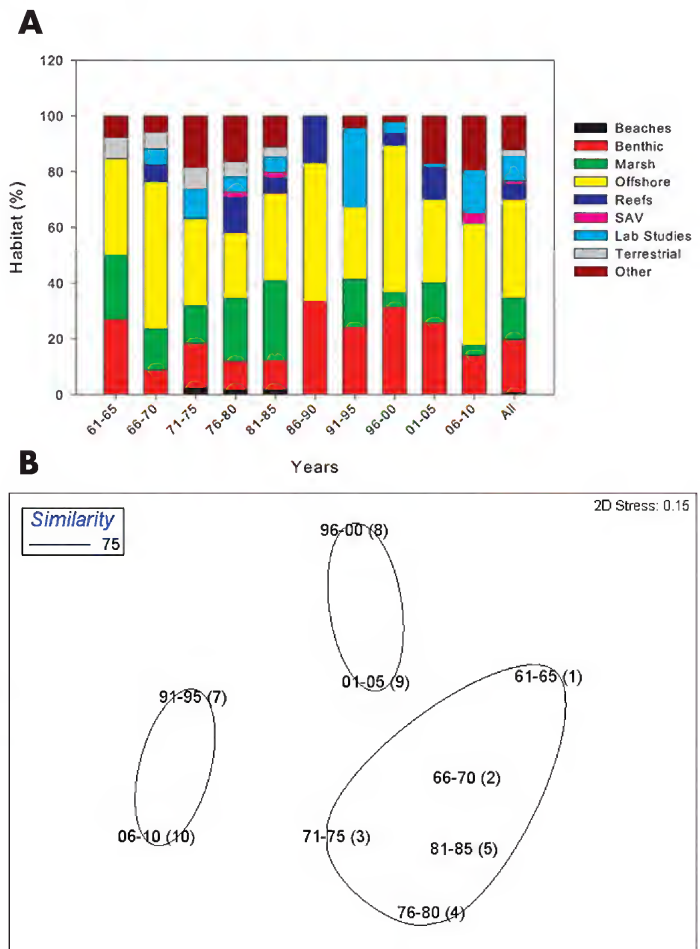
Figure 8. *Summary of (A) habitat type representation published in the journal by date set and (B) MDS plot of square-root transformed data in panel A.*

were by Mexican authors (Posada and Franks 2008), whereas from 1996–2000 25% of the articles in GCR were authored by Mexican nationals (Figure 4A). Overall, the *Proceedings* does not have as diverse an authorship as GRR/GCR (authors from other U.S. regions, Canada, Europe and Asia were rarely, if ever represented), but similar trends in the decrease of authors from the GOM and the southeastern United States and an increase in Caribbean and Mexican authors over time are consistent between both journals.

Although Posada and Franks (2008) list 40 different scientific thematic areas represented by publications in the *Proceedings*, these can be condensed into 6 general subject areas (management, life history, aquaculture, toxicology, inventories and other) to enable comparison with GRR/GCR subject categories. A major difference between the *Proceedings* and GRR/GCR is the high percentage of papers related to management in the *Proceedings*; 49.8% in the first 30 years (1948–1977) and 25.4% in the last 27 years (1978–2004) (Posada and Franks 2008). In contrast, management papers never represented more than 10% of papers published in GRR/GCR through 2000, and only represented 15–16% of papers since that time (Figure 6A), reflecting the different

scope of the two journals. Life history papers were the second most common category in the *Proceedings*, representing 27.4% of papers from 1948–1977 and 40% of papers from 1978–2004 (Posada and Franks 2008). These percentages are higher than seen in GRR/GCR (Figure 6A), although life history is one of the three top categories in our journal. Finally, aquaculture increased in importance to represent 9.7% of publications from 1978–2004 in the *Proceedings*, although the number of aquaculture publications noticeably declined beginning in 2002 (Creswell 2008), similar to trends seen in GCR/GRR (Figure 6A).

The taxonomic diversity of the *Proceedings* is similar to that of GRR/GCR, with the exception that microorganisms and plants were not represented in the thematic areas listed by Posada and Franks (2008). Multi-taxa studies dominate the *Proceedings*, but this is likely due to the inability to differentiate among taxa included in several thematic areas (stock assessement, harvesting, fisheries management) in Posada and Franks (2008). Overall, fish make up the most abundant single taxon group in the *Proceedings* (25%, Posada and Franks 2008), similar to the overall percentage of fish studies in GRR/GCR (27.8%, Figure 7A). Interestingly, Mol-

lusca makes up a much higher percentage in the *Proceedings* (15.5%) from 1978–2004 (Posada and Franks 2008) than during any time period in GRR/GCR (Figure 7A). In contrast, Crustacea represent 17%–50% of taxa in GRR/GCR during all date sets (Figure 7A) in comparison to a maximum of 14.6% in the *Proceedings* (Posada and Franks 2008).

Journal citation trends

An *ISI Web of Science*™ cited reference search found that, of the 303 published articles between 1961 and 1999 in GRR, 220 have been cited a total of 1,743 times (Table 3), and 72% of the articles published in GRR have been cited at least one time. Dawson (1966) was the most cited article, with a total of 76 citations. Of the five most cited articles, three of them were authored or co-authored by C.E. Dawson and included his bibliography on fish anomalies and updates to the bibliography (Dawson 1966, 1971, Dawson and Heal 1976).

A second search of GRR was done using *Publish or Perish*™ software and *Google Scholar* (Harzing 2010). This search resulted in 155 articles cited 1,378 times, with 3 cited 40+ times, 12 cited 20–39 times, 28 cited 10–19 times, and 112 cited 1–9 times (Table3). Overall, 51 % of published articles were cited at least once. According to this search, C.E. Daw-

son's bibliography of fish anomalies was cited 110 times and was the most cited article published in GRR. However, this appears to be a combination of Dawson (1966), Dawson and Heal (1976), and possibly Dawson (1971) (Table3).

Of 152 published articles in GCR, the *ISI Web of Science*™ search noted 77 articles have been cited a total of 323 times (Table 3) and showed that 51% of published articles have been cited at least once. Of the 77 articles, the most cited article was Cowen et al. (2003), which was cited 39 times. Of the 6 most cited articles from the *ISI Web of Science*™ search, 5 of the 6 appeared in the special issue "Caribbean Marine Protected Areas: Practical Approaches to Achieve Economic and Conservation Goals: Proceedings of a Symposium at the 54th Annual Meeting of the Gulf and Caribbean Fisheries Institute Symposium, Turks and Caicos, November 2001" published in 2003 as GCR 14(2).

The *Publish or Perish*™ and *Google Scholar* search resulted in 98 articles cited 430 times (Table 3), with 64% of the articles cited at least once. Eight articles were cited 212 times, 18 articles were cited 103 times, and 72 articles were cited 115 times (Table 3). Once again, Cowen et al. (2003) was the most cited article (52 times) Similar to results from the

TABLE 4. *Listing of marine science journals that have cited articles in Gulf Research Reports (GRR) and Gulf and Caribbean Research (GCR).*

Journal Name	GRR (1965-2010)	GCR (2000-2010)
Bulletin of Marine Science	76	9
Estuaries	56	
Fishery Bulletin	55	
Journal of Experimental Marine Biology and Ecology	53	5
Marine Ecology Progress Series	50	22
Marine Biology	47	7
Transactions of the American Fisheries Society	41	
Journal of Crustacean Biology	35	
Estuarine, Coastal Shelf Science	33	
Journal of Shellfish Research	29	
Hydrobiologia	29	
Aquaculture	29	
Zootaxa	26	11
Crustaceana	26	
Gulf Research Reports	25	
Journal of Fish Biology	22	9
Ecology	18	
Proceedings of the Biological Society of Washington	17	
Revista de Biología Tropical	17	
Copeia	16	
Environmental Biology of Fishes	16	6
Canadian Journal of Fisheries & Aquatic Sciences	15	
Contributions in Marine Science	15	
Journal of the Marine Biological Association (UK)		8
Coral Reefs		7
Fisheries Research		7

ISI Web of Science™, The *Publish or Perish*™ and *Google Scholar* search identified 8 articles in the Caribbean Marine Protected Areas volume 14(2) that were cited 10+ times.

Finally, we were interested in which journals cite articles from GRR and conducted an *ISI Web of Science*™ search from 1965–July 2010. Twenty three journals cited an article from GRR at least 15 times (Table 4). We conducted a similar search for GCR from 2000–July 2010, and identified 10 total journals (including 3 that did not cite articles in GRR) citing GCR articles between 6-22 times (Table 4). These results illustrate both GRR and GCR are well cited within many top-tier journals that publish marine-oriented articles, although it is important to note GRR has been in existence for 50 years whereas GCR has only been published for the past 10 years.

In reviewing the citation history of GRR and GCR articles captured using the *ISI Web of Science*™ "cited reference" search, it immediately became apparent there were numerous errors in the search results. For GRR, about 28% of the articles were cited incorrectly. For GCR, the percentage of error in citation was slightly lower at 20%. Citation errors included misspelled author's name, and incorrect volume numbers, dates, and pages. The worst corruption of a single reference, cited incorrectly twice, was:

Heard, R.W. 1952. Observations on the food and food habitats of clapper rails, *Rallus longirostis* (Boddaert), from tidal marshes along the East and Gulf Coasts of the United States. *Gulf Resource Report* 2 392-412.

The correct citation is:

Heard, R.W. 1982. Observations on the food and food habits of clapper rails, *Rallus longirostris* (Boddaert) from tidal marshes along the East and Gulf Coasts of the United States. *Gulf Research Reports* 7(2):125-135.

The two citing articles had included the bad citation exactly the same in their literature cited with all four elements (journal title, year, volume, and pagination) incorrect. One was found using *ISI Web of Science*™ and the other using *Google Scholar* (http://scholar.google.com/).

Moed and Vriens (1989) quantified citation database errors in cited literature using a small sample of 29 articles and found most of the errors in citations were author errors. The 20-28% error rate for GRR and GCR are similar to those found by Benning and Speer (1993), who compared the citation errors in library literature with those reported in medical literature. They found incorrect citations in 27% of the references in library literature and a 28% error in medical literature citations. The rate of error is fairly common, with studies showing percentage of error from various journals ranging from 10.7% to 50% (Smith 1981). Citation errors found in *ISI Web of Science*™ were corrected during the course of this study.

Summary

Our analysis shows that GRR/GCR fulfills an important niche in the marine science literature. Although GRR/GCR is considered a regional journal, it represents an international region, and this influence is seen in the geographic distribution of authors and study sites as well as the subject matter and taxa covered. From its beginning as a small, editor-reviewed journal primarily publishing the results of scientists from GCRL, GCR has grown into a respected peer-reviewed journal with contributions from scientists from many national and international institutions. However, throughout its growth, GCR has remained true to its initial mission of disseminating knowledge regarding the biota and related information from the GOM and adjacent (Caribbean) waters.

Acknowledgments

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APPENDIX 1. *Topics and categories used in this paper and details associated with each.*

Topics	Category	Detail
Author large-scale geographic distribution	USM/GCRL Non-USM/GCRL	
Author small scale geographic distribution	GOM	All Gulf of Mexico - Texas through west Florida
	Atlantic SE	Southeastern US Atlantic coastal states—Virginia to east Florida, including Gainesville, Florida and Florida Keys
	Other US	All non-GOM and non-Atlantic SE states
	Mexico	All Mexican states
	Caribbean	All countries in the Caribbean Sea, including Bermuda and Brazil
	Canada	All Canadian provinces
	Europe	All European Countries, including Germany, Sweden, Denmark
	Asia	Japan
Geographic area of study site (some data were partitioned into multiple areas if the samples were from more than one site)	MS only	All areas of Mississippi
	Other GOM	Texas, Louisiana, Alabama, west Florida
	Atlantic SE	Southeastern US Atlantic coastal states—Virginia to east Florida
	Caribbean	All countries in the Caribbean Sea, including Bermuda and Brazil
	Mexico	All Mexican states
	Other	Bibliographies, legal aspects of salt marsh systems
Subject area	Taxonomy	Also includes systematics and species distributions
	Management	Also includes stock structure, fisheries models, gear efficiencies and socio-economics
	Physiology	Also includes morphology, gross physical abnormalities and histology
	Life History	Also includes reproductive biology, feeding and growth
	Parasites	Also includes diseases and symbionts
	Inventory	Also includes surveys, distributions, range extensions, monitoring, species lists, bibliographies, single observations
	Toxicology	Also includes pollution
	Ecology	Also includes species assemblages and trophic analyses
	Aquaculture	All aspects of aquaculture
	Oceanography	Includes chemical, physical and geological oceanography

APPENDIX 1. Continued...

Topics	Category	Detail
	Other	Includes genetics, behavior, methods papers, hurricane balls, law and tidal wracks
Taxa	Microorganisms	Viruses, bacteria, protists (ciliates, dinoflagellates, diatoms, foraminiferans) and fungi
	Crustacea	Crustaceans as the primary subject
	Mollusca	Molluscs as the primary subject
	Other invertebrates	All invertebrates other than crustaceans and molluscs
	Fish	Fish as the primary subject (fish feeding studies generally in this category rather than in Multiple Taxa)
	Higher vertebrates	All vertebrates other than fish
	Plants	Algae, seagrasses, salt marshes, mangroves, etc. as the primary subject
	Multiple taxa	Two or more of the above taxonomic categories as the primary subjects (includes faunal surveys, benthic studies, zooplankton studies, etc.)
	Non-taxa	Chemistry, geology, history, hydrology, marine law, marine reserves, methods, nutrient flux, etc.
Habitats	Reefs	Oyster, coral and artificial reefs (primarily coral reefs)
	Open water	Bays, sounds, nearshore waters and offshore waters
	Marsh	Salt and fresh water marshes; barrier island ponds
	Submerged aquatic vegetation	Seagrasses in shallow sounds, bays and low salinity estuaries
	Benthic	Shallow water (shoreline and estuarine) and deep water environments
	Beaches	Mainland and barrier island beaches; swash zone
	Laboratory studies	Experimental laboratory studies (organisms associated with benthic, demersal and pelagic habitats)
	Terrestrial	Upland forests, grasslands, etc.
	Other	Multi-habitats associated with MPAs and marine reserves, management and design of MPAs, fisheries management, fisheries economics, geology, rivers, and bibliographies

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Distribution and Abundance of Introduced Fishes in Florida's Charlotte Harbor Estuary

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DISTRIBUTION AND ABUNDANCE OF INTRODUCED FISHES IN FLORIDA'S CHARLOTTE HARBOR ESTUARY

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Abstract: A growing number of non-native fishes have been introduced into Florida waters in recent years, yet little information has been available on their distribution and abundance in southwest Florida. The ichthyofauna of the Charlotte Harbor estuary, Florida, was intensively sampled from 1989 through 2007. We collected eight introduced fish taxa: African jewelfish (*Hemichromis letourneuxi*), blue tilapia (*Oreochromis aureus*), brown hoplo (*Hoplosternum littorale*), grass carp (*Ctenopharyngodon idella*), Mayan cichlid (*Cichlasoma urophthalmus*), sailfin catfishes (*Pterygoplichthys* spp.), spotted tilapia (*Tilapia mariae*), and walking catfish (*Clarias batrachus*). These fishes were found principally in tidal rivers, especially the Caloosahatchee River. Other introduced species, such as Asian swamp eel (*Monopterus albus*), blackchin tilapia (*Sarotherodon melanotheron*), and pike killifish (*Belonesox belizanus*), are known to occur in neighboring bay systems but have yet to be reported in the Charlotte Harbor estuary. Continued monitoring will help us detect additional species that are introduced to the estuary, expansions in the ranges of documented species, and assemblage-level changes.

Key Words: Charlotte Harbor, Caloosahatchee River, Florida, cichlids, exotic fishes

Introduction

As human activity continues to expand in Florida, a growing number of non-native plants and animals, including fishes, are being introduced to the state. To date, more than 100 species of introduced fishes have been collected in Florida waters. Of these, 23 are considered to be "established" (i.e., appear to have permanent populations), and another nine are considered to be "possibly established" (Shafland et al. 2008).

Introduced fishes can affect native ichthyofauna by competing for resources such as food or habitat, introducing diseases or parasites, and through predation (Hill 2002, AFS 2008, FWC 2008). Fish introductions have affected native ichthyofaunas (e.g., Hedrick et al. 1998, Utah Division of Wildlife Resources 2002, Balirwa et al. 2003, Pilger et al. 2008) or ecosystems (e.g., Courtenay and Robins 1975, Leslie et al. 1987, Baxter et al. 2004, Reissig et al. 2006) in a variety of locations. Often, however, the effects that introduced fish species have on the native fauna are not known (Hill 2006). Detailed environmental data, especially baseline data collected before a species is introduced, are usually lacking, making it hard to detect impacts or to separate them from normal biological variability. For example, Trexler et al. (2000) found "little evidence of ecological effects of introduced fishes on the native freshwater communities in southern Florida" but concluded that "cryptic or delayed effects may have been overlooked." Nevertheless, fish introductions are usually considered undesirable due to their potential for causing unwanted changes in native populations and ecosystems (AFS 2008, FWC 2008, Leprieur et al.

2008, 2009, Vitule et al. 2009).

Knowing the distribution and abundance of an introduced species is an important step in understanding its potential impacts on an ecosystem. Trends in population size and distribution over time can be used to project a species' long-term status. Focusing subsequent research on the areas where an introduced species is most abundant may improve understanding of that species' habitat requirements and effects on native fauna. This information would help those charged with making management decisions, including those prohibiting future introductions or limiting the spread of a species that has been introduced.

Although the status and distribution of fishes introduced in many areas of Florida have been described (FWC 2008, FMNH 2008, Shafland et al. 2008), little information has been available on fishes introduced into the Charlotte Harbor area. Wang and Raney (1971) conducted the first extensive ichthyological survey of the Charlotte Harbor estuary in 1968–1969 and collected no introduced fishes. Poulakis et al. (2004) compiled all available data to produce a comprehensive list of fishes collected in the Charlotte Harbor estuarine system; five introduced species were included. Much of the information in the Poulakis et al. (2004) synthesis was derived from data collected by the Florida Fish and Wildlife Conservation Commission's Fisheries–Independent Monitoring (FIM) Program from 1989 through 2002. We used FIM Program data collected from 1989 to 2007 to update and describe in detail the occurrences and distributions of fishes introduced into the Charlotte Harbor estuary, includ-

ing information on additional areas sampled in recent years (Caloosahatchee River, southern Matlacha Pass, and southern Pine Island Sound).

Materials and Methods

Study location

Charlotte Harbor is a relatively large (ca. 700 km²; Hammett 1990), shallow estuary on the southwest coast of Florida (Figure 1a). The region is subtropical, with air temperatures averaging 16°C in winter (December–January) and 27°C in summer (July–August) (Hammett 1990). Yearly rainfall averages 134 cm, as much as 70% of it typically falling in summer (Taylor 1974). Occasional freezes and tropical cyclones can have considerable effects on the system (Hammett 1990, Stevens et al. 2006).

Three major rivers provide fresh water to the estuary: the Peace and Myakka rivers enter Charlotte Harbor near its northern terminus, and the Caloosahatchee River enters the harbor at its southeastern end. Considerable water is exchanged with the Gulf of Mexico through San Carlos Pass, Boca Grande Pass, and several smaller inlets. Therefore, salinity varies widely both geographically and temporally. Varying degrees of vertical stratification are seen in the estuary during the warmer months (Estevez 1998), contributing to seasonal hypoxia in the underlying water mass that may affect portions of upper Charlotte Harbor and the lower Peace River (Fraser 1997). Much of the shoreline is characterized by mangroves (principally *Rhizophora mangle* and *Avicennia germinans*), with some areas of sand beach, salt marsh (dominated by *Spartina alterniflora* and *Juncus roemerianus*), and seawalls. Substrate varies from sand to mud, with large expanses of seagrasses (*Thalassia testudinum*, *Halodule wrightii*, *Syringodium filiforme*, and *Ruppia maritima*) in shallow areas.

Charlotte Harbor remains one of the least altered estuaries in peninsular Florida; much of the surrounding land is protected by public ownership. However, past and present activities related to increased development in the watershed have significantly impacted the estuary (Charlotte Harbor National Estuary Program 2000). These activities include shoreline hardening, channelization, water withdrawal from tributaries and aquifers, manipulation of water-flow regimes (Caloosahatchee River), increased nutrient input, and scarring of seagrass beds by boat propellers. Development is densest near the mouths of the Caloosahatchee (cities of Cape Coral and Fort Myers) and Peace (cities of Port Charlotte and Punta Gorda) rivers.

Sample collection

Fish and certain invertebrates (crabs and shrimp of commercial importance) have been sampled in the Charlotte Harbor estuary by the FIM program since 1989; this paper includes data collected through 2007. Samples were taken seasonally (spring and fall) from 1989 to 1995 and monthly thereafter. The initial sampling area was located north of Pine Island Sound and Matlacha, including Gasparilla Sound, northern Matlacha Pass, and the tidal portions of the Peace and Myakka rivers. The sampling area was expanded in 1994 to include Pine Island Sound and in November 2003 to include southern Matlacha Pass, tidal portions of the Caloosahatchee River (upstream to Franklin Lock), and the Orange River. Until 1998, 15 fixed stations located in the upper harbor and Peace River were also sampled monthly.

Use of a range of sampling gear allowed us to sample much of the estuarine ichthyofauna. Shallow (≤1.8 m) habitats were sampled with a 21.3 m nylon bag seine (1.8 m depth, 3.2 mm mesh, 1.8 m × 1.8 m center bag). Deeper areas (>1.8 m and ≤7.6 m) were sampled with a 6.1 m otter trawl (38 mm mesh with 3.2 mm mesh liner). Gear of these types and sizes is more efficient in capturing small fishes and crustaceans (Comp and Seaman 1985) than larger, more mobile animals (Kupschus and Tremain 2001). Therefore, 183 m center–bag haul seines (3.0 m depth, 38 mm mesh), 183 m center–bag purse nets (3.3 m depth, 50 mm mesh), and 180 m gill nets (2.0 m depth, 51 to 152 mm mesh) were used periodically to sample larger fish, allowing us to sample a wide variety of sizes and types of fishes simultaneously.

A stratified-random design was used to select sampling sites. Sampling locations were chosen randomly without replacement from a universe of 0.2 × 0.2 km sites that contained suitable habitat. Samples were collected principally during the day (both day and night sampling were conducted prior to 1996) and processed in the field. All fish and selected invertebrates in each sample were identified to the lowest practical taxon and counted. A maximum of 40 randomly selected individuals of each taxon were measured to the nearest millimeter standard length (SL). Extremely large catches were subsampled with a modified Motoda box splitter after less abundant species had been removed and processed (Winner and McMichael 1997). Representative samples of most species were retained and reidentified in the laboratory for quality control; the remaining fish were returned to the water. Species that could not be identified in the field were retained and identified in the laboratory. Nomenclature follows Nelson et al. (2004).

Date, location (latitude and longitude), depth, and bottom and shoreline descriptors (e.g., substrate and vegetation type), water temperature (°C), salinity, and dissolved oxygen (mg/l) were recorded at each sampling site. The hydrologic variables were measured at the water surface and at depth intervals of 1.0 m to the bottom.

Data analysis

To examine the geographic distributions of introduced species, we plotted the locations and sizes of individual catches (fish/haul), regardless of sampling gear. We tabulated numbers of fish collected by salinity category, modified
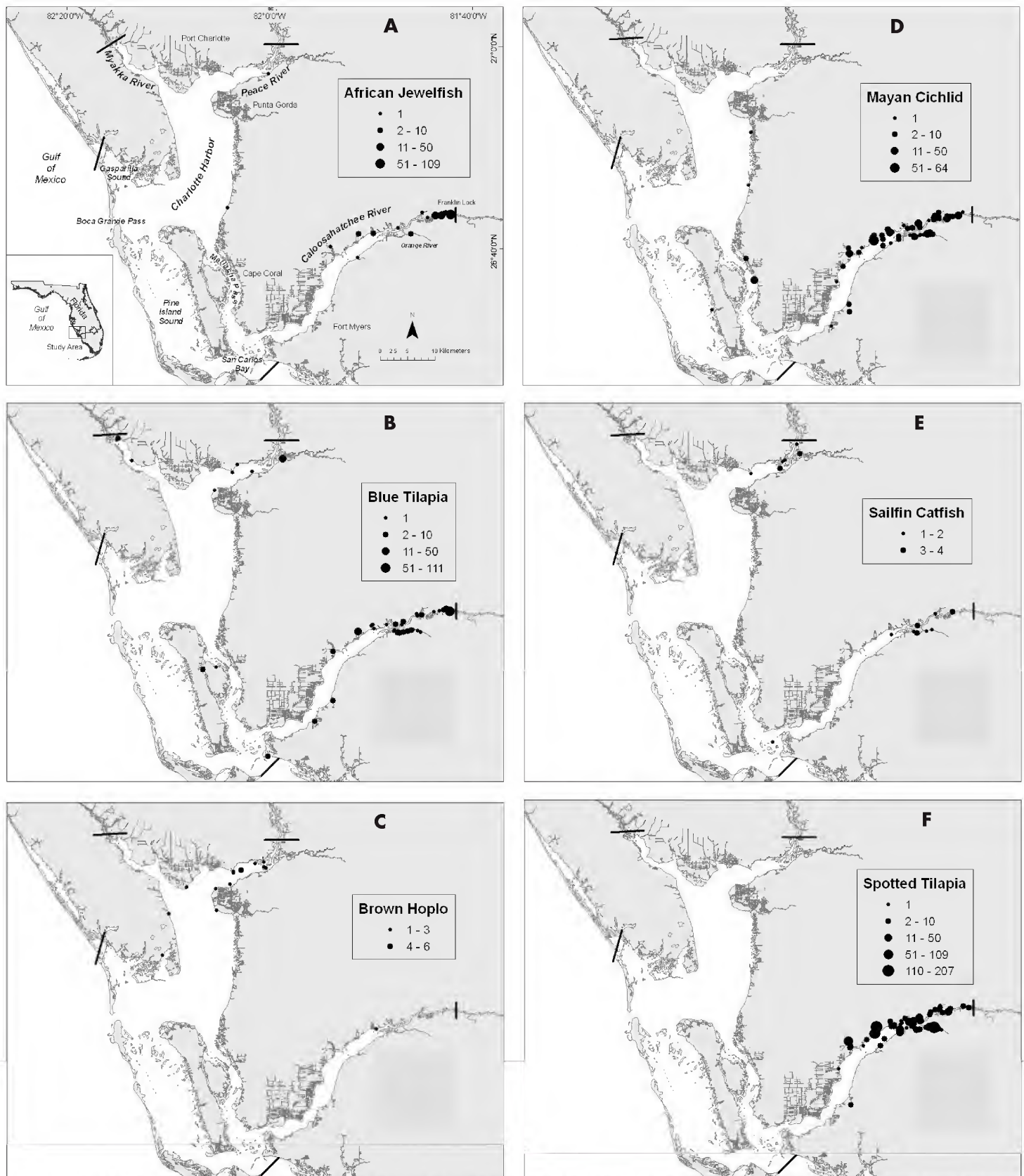
Figure 1. *Catches of introduced species made during the study period in Charlotte Harbor ("0" catches not shown). Dark bars delineate boundaries of sampling area.*

from the Venice system (Anonymous 1958): limnetic (<0.5), oligohaline (0.5–4.99), low mesohaline (5–11.99), high mesohaline (12–17.99), polyhaline (18–29.99), and euha-

line (≥30). For introduced species that were collected in sufficient numbers (at least several hundred individuals), catch data from the area and sampling gear of highest abundance

were analyzed as follows: catches were standardized to area sampled (fish/100 m²), geometric mean fish density ± 95% confidence limits (Sokal and Rohlf 1981) were calculated, and these densities were plotted against month to reveal seasonal trends. Monthly lengths were overlaid on the density plots to evaluate spawning seasonality and recruitment.

Results and Discussion

We collected 21,524 samples containing 7,459,363 individuals. More than 260 taxa of fishes and commercially important crustaceans were represented, including eight species of introduced fishes. The grass carp (*Ctenopharyngodon idella*) is represented by only a single specimen, captured in the upstream portion of our sampling area in the Caloosahatchee River in June 2005. These sterile grass carp are used in Florida to help control aquatic vegetation (Shafland et al. 2008), and this fish is probably an escapee from a stocked pond or lake. The walking catfish (*Clarias batrachus*) is represented by two specimens collected in a single sample near the mouth of the Myakka River in September 1994. Although this species is established in the Peace River watershed (Fraser 2007) and is abundant in some freshwater

northwest Africa, where it inhabits freshwater and brackish habitats of tidal rivers (Schofield et al. 2007). The Florida population likely was established by fish that escaped from an ornamental fish farm into Dade County waters in the early 1960s (Courtenay et al. 1974). The range of this species has expanded throughout south Florida, extending north to the Alafia River on Florida's west coast (Shafland et al. 2008).

We collected 197 African jewelfish ranging from small individuals to adults (19–53 mm SL). The first was taken in September 2003 in the Peace River. Another specimen was collected on the eastern shore of Charlotte Harbor in 2006. The rest were collected in the Caloosahatchee River and adjacent Orange River at shallow sites sampled with 21.3–m seines (Figure 1a); these collections were analyzed further. Most of the African jewelfish collected in this area were found in freshwater and oligohaline areas (Table 1). Small individuals (< 25 mm SL) were collected only in October (n = 2), November (n = 3), and December (n = 3). Although monthly trends in mean SL were not apparent, fish were most abundant in late fall and winter (Figure 2a), suggesting that spawning took place principally in fall.

TABLE 1. Numbers of introduced species collected during 1989-2007 in Charlotte Harbor estuary by salinity category. Categories are based on the Venice System (Anonymous, 1958).

Species	Salinity						Total
	<0.5	0.5-4.99	5-11.99	12-17.99	18-29.99	≥30.0	No. of fish
African jewelfish	160	33	1	2	1	0	197
Blue tilapia	52	200	18	10	4	0	284
Brown hoplo	16	9	3	1	0	0	29
Mayan cichlid	156	148	79	66	12	1	462
Sailfin catfish	23	5	1	0	0	0	29
Spotted tilapia	487	446	76	28	1	0	1,038

ponds adjacent to our sampling area (pers. obs.), it has been unsuccessful in colonizing the estuarine portions of Charlotte Harbor, presumably due to poor salinity tolerance or preference for lower salinities. The six other introduced taxa collected—African jewelfish (*Hemichromis letourneuxi*), blue tilapia (*Oreochromis aureus*), brown hoplo (*Hoplosternum littorale*), Mayan cichlid (*Cichlasoma urophthalmus*), sailfin catfishes (*Pterygoplichthys* spp.), and spotted tilapia (*Tilapia mariae*)—were more abundant in the study area. Species profiles and distributional information for these fishes are given below.

African Jewelfish (*Hemichromis letourneuxi*)

The African jewelfish is a relatively small (usually <75 mm total length in Florida; Shafland 1996) cichlid native to

Fraser (2007) lists the African jewelfish as being established in the Peace River, based on evidence of a reproducing population in freshwater areas; however, it is not abundant (Champeau et al. 2009). This species is also present in tidal creeks on the eastern shoreline of Charlotte Harbor (A.J. Adams, unpublished data, Mote Marine Laboratory, Pineland, FL).

Blue tilapia (*Oreochromis aureus*)

The blue tilapia is native to North Africa and the Middle East and has been introduced in many parts of the world for aquaculture (Shafland and Pestrak 1982). It was released into Hillsborough County waters in the 1960s in aquatic weed control experiments. It was also promoted as a food and game species, which prompted anglers to release it in
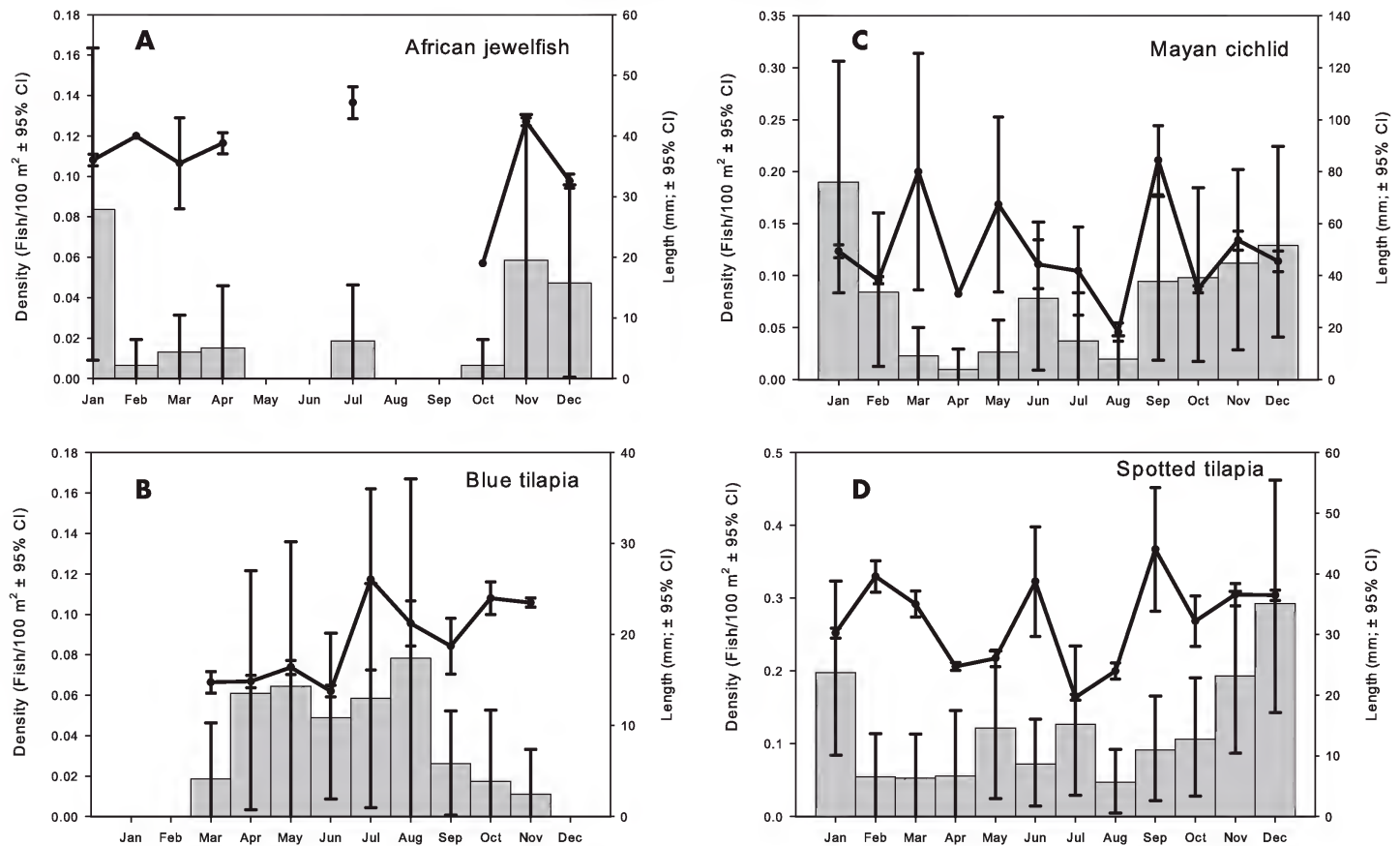
Figure 2. *Estimated densities (histogram; fish/100m²) and standard length (lines; mm; ± 95% CI) of abundant introduced species collected with 21.3–m seines during 2003–2007 in the tidal portion of the Caloosahatchee River and vicinity by month.*

other areas (Courtenay et al. 1974). It rapidly became the most widespread introduced species in Florida (Courtenay et al. 1974, Shafland et al. 2008), and in some lakes it even supports a small commercial fishery.

We collected 284 blue tilapia ranging from small individuals to large adults (9–280 mm SL). The first were collected in December 1991, when three individuals were captured on the southern shoreline of the Peace River, about 14 km above the river's mouth. The largest catch contained 111 individuals; this collection was in the upstream portion of our sampling area in the Caloosahatchee River, near Franklin Lock. Most catches were made at sites in the tidal rivers, particularly in the Caloosahatchee and Orange rivers (Figure 1b). Data collected in the Caloosahatchee area (21.3 m seine catches; n = 201) were examined in more detail. Blue tilapia in this area were almost exclusively found in low-salinity habitats (mainly < 12; Table 1). Spawning apparently takes place only during the warmer months; we collected small individuals (< 25 mm SL; n = 32) from March to October. Mean fish length was smallest from March to June, suggesting most spawning occurred during this period (Figure 2b). Few fish were collected during the rest of the year (Figure 2b). This is consistent with a reported minimum tempera-

ture of 20° for spawning (FWC 2008).

The blue tilapia has been present in the Peace River drainage since at least 1973 (Champeau 1990, Fraser 2007) and remains an established and abundant component of the ichthyofauna of the Peace River (Champeau et al. 2009) and other freshwater portions of the Charlotte Harbor watershed. Our data indicate that while individuals occasionally enter brackish areas, this species has not been successful in colonizing the Charlotte Harbor estuary.

Brown hoplo (*Hoplosternum littorale*)

The brown hoplo is native to fresh and brackish waters of northeastern South America and Panama (Nico et al. 1996). It was first reported in Florida in 1995, when 33 specimens were captured and hundreds more were observed in the Indian River Lagoon system (Nico et al. 1996). The source of this species' introduction remains unknown, although possibilities include release by hobbyists, escape from aquaculture ponds, and introduction as a food fish (Nico et al. 1996). Since this catfish was discovered, its range has expanded rapidly. It is now present throughout much of central and south Florida (Shafland et al. 2008) and has even become a major dietary item of the common snook (*Centropomus undecimalis*), an important game fish in this area (Ste-

vens et al. 2010). The ability to breathe air by gulping has allowed it to survive in water with low levels of dissolved oxygen and has probably facilitated its spread (Nico et al. 1996).

We collected 29 brown hoplos, ranging from small individuals to adults (17–172 mm SL). The first specimen was captured in September 2001 near the mouth of the Peace River. Although in its native range this species inhabits brackish areas with salinities up to 16 (Nico et al. 1996), it appears to be confined principally to freshwater habitats in the Charlotte Harbor system, where it has become quite abundant (Fraser 2007, USGS 2008). In fact, most of our specimens were collected in or near the mouth of the Peace River (Figure 1c) shortly after the passage of Hurricane Charley (August 13, 2004), which caused massive freshwater runoff in the Peace River watershed (Stevens et al. 2006). The brown hoplo has also been documented in the Myakka and Caloosahatchee rivers (Peebles et al. 2006, USGS 2008).

Mayan cichlid (*Cichlasoma urophthalmus*)

The Mayan cichlid is native to the Atlantic slope of Central America. The origin of the Florida population is not known, although it was first reported in the Everglades in 1983 (Loftus 1987). It is well established in south Florida (Trexler et al. 2000, Matamoros et al. 2005, Shafland et al. 2008), and its range has expanded northward, with established populations to at least Melbourne and Tampa Bay on Florida's east and Gulf coasts, respectively (Paperno et al. 2008).

We first collected the Mayan cichlid in December 2003, when 11 individuals were captured in a single sample in Matlacha Pass. A few were taken on the eastern side of Charlotte Harbor near tidal creeks, and one was collected in Pine Island Sound. The largest catch, at a site on the north bank of the Caloosahatchee River about 19 km above its mouth, was 64 specimens. Most (n = 435) of the 462 specimens taken during this study were collected with 21.3 m seines in the Caloosahatchee and Orange rivers (Figure 1d), where this fish is particularly abundant in backwater areas (Stevens et al., 2010). Data from the Caloosahatchee River area were examined further. The Mayan cichlid has an affinity for brackish conditions in its native range (Martinez–Palacios et al. 1990, Chavez–Lopez et al. 2005, USGS 2008), and we also collected them at sites ranging from limnetic to high mesohaline (Table 1). The presence of both juveniles and adults (13–288 mm SL) indicates that this species is established and breeding in the Charlotte Harbor system. Most (26 of 30) small individuals (< 25 mm SL) were collected from June to December, suggesting an extended spawning season through the warmer months. Smallest mean lengths during June-August may reflect peak spawning during this period, followed by increased abundance as these young recruit to our sampling gear (Figure 2c). This contrasts with

the findings of Faunce and Lorenz (2000), who noted that breeding activity of Mayan cichlids in the southeastern Everglades was limited to spring (April to June).

Adams and Wolfe (2007) also documented the presence of Mayan cichlids in tidal creeks along the eastern shoreline of Charlotte Harbor. They proposed that these tidal creeks provide connectivity between the estuarine habitats of Charlotte Harbor and altered upland habitats and concluded that populations established in upland habitats periodically (during the rainy season) invade estuarine habitats but do not appear to be established or to breed there.

Sailfin catfish (*Pterygoplichthys* spp.)

Sailfin catfish are native to South and Central America (Nico and Martin 2001). These popular aquarium fishes, known as "plecos" in the pet trade, were probably introduced into Florida by escaping or being released from ornamental fish farms or aquariums. Several species of sailfin catfishes and similar suckermouth catfishes (*Hypostomus* spp.) have been well established in south and central Florida rivers and canals since the 1980s (Shafland 1996, Hill 2002, Nico et al. 2009).

We first collected sailfin catfish in the Charlotte Harbor estuary in August 1996. We collected a total of 29 specimens, ranging from small individuals to adults (21–374 mm SL), evidence that they are established and breeding in the Charlotte Harbor system. However, they appear to be confined principally to low-salinity areas (Figure 1e), and are well-established and abundant in tributaries of Charlotte Harbor (Peebles et al. 2006, Fraser 2007, Champeau et al. 2009). Although the systematics of sailfin catfish remains unclear, at least four species, the vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*), the Orinoco sailfin catfish (*P. multiradiatus*), the Amazon sailfin catfish (*P. pardalis*), and *P. parnaibae*, may occur in the estuary (R. Ruiz–Carus, pers. comm., Florida Fish and Wildlife Conservation Commission, St. Petersburg, FL).

Spotted tilapia (*Tilapia mariae*)

The spotted tilapia is native to western Africa (Taylor et al. 1986). In Florida, it was first reported in 1974, in Dade County (FMNH 2008). It has since become abundant in canals throughout southeastern Florida (Shafland 1996), and its range has expanded north on Florida's east coast to Melbourne (Shafland et al. 2008).

We collected 1,038 spotted tilapia with 21.3 m seines from the upstream portion of our sampling area in the Caloosahatchee and Orange rivers (Figure 1f), where it was relatively abundant. Five of our catches contained more than 50 fish, and the largest catch had 207. The spotted tilapia is most numerous in backwater habitats in this area (Stevens et al., 2010). Our spotted tilapia data were examined for distributional trends. Most were collected at low-salinity (freshwater and oligohaline) sites (Table 1). Specimens ranged from small individuals to large adults (12–265 mm SL),

indicating a well-established breeding population. Small individuals (< 25 mm SL) were collected in all months and were most abundant in November (n = 11) and December (n = 10), suggesting a protracted spawning period with peak reproductive activity in late fall. This spawning pattern is reflected in the absence of a clear seasonal pattern of mean fish length, and maximum fish abundance during the winter months (Figure 2d). Peak spawning of spotted tilapia is reported to take place from November to March in south Florida (FWC 2008).

Other species

Other non–native species have been reported in freshwater areas of the Charlotte Harbor watershed but were not represented in our samples. These include the Nile tilapia (*Oreochromis niloticus*), Oriental weatherfish (*Misgurnus anguillicaudatus*), and pirapitinga (*Piaractus brachypomus*) (Shafland et al. 2008, USGS 2008). Single specimens of the Guayas cichlid (*Cichlasoma festae*), Mozambique tilapia (*Oreochromis mossambicus*), and small–scaled pacu (*Piaractus mesopotamicus*) have also been reported, although these identifications are questionable (USGS 2008). Of these species, only the oriental weatherfish is thought to be established in the system (Fraser 2007, Shafland et al. 2008).

A number of introduced fishes, including the Asian swamp eel (*Monopterus albus*), blackchin tilapia (*Sarotherodon melanotheron*), and pike killifish (*Belonesox belizanus*), could eventually enter the Charlotte Harbor system. They are established in Tampa Bay and southeast Florida. The blackchin tilapia has been successful in colonizing the higher-salinity areas of Tampa Bay (Courtenay et al. 1974). Turner and Snelson (1984) found reproducing populations of the pike killifish at salinities ranging from 0 to 50 in southeast Florida, and Florida populations of the Asian swamp eel also tolerate brackish conditions (Schofield and Nico 2009).

Conclusions

Charlotte Harbor has considerably fewer introduced fish species than adjacent areas. The Tampa Bay drainage, to the north, has about twice as many introduced species, and the Dade and Broward county area of Florida, to the southeast, has about five times as many introduced species (USGS 2008). We suggest two explanations for this difference. First, these areas, although close to Charlotte Harbor, are more heavily populated and developed than Charlotte Harbor is, and the increased habitat modification associated with such urbanization is thought to facilitate the establishment of introduced species (Shafland 1996, Adams and Wolfe 2007, Leprieur et al. 2008). Second, there have been more aquaculture facilities in the Tampa Bay drainage and in southeast Florida than in the Charlotte Harbor area (UF DFAS 2008), and these facilities are thought to be the source of most fish introductions (Courtenay et al. 1974, USGS 2008).

Many of the introduced fishes reported in Florida are from tropical or subtropical areas of Africa, Asia, or South America. In Florida, particularly south Florida, these fishes have the potential to survive and become established because the climate is similar to that of their native habitat. The ranges of some of these species are thought to be restricted by limited cold tolerance (Shafland et al. 2008). For example, the distribution of the spotted tilapia, fairly abundant in our Caloosahatchee River samples but not collected farther north, may be thermally limited (lower lethal temperature = 11.2°C; Shafland and Pestrak 1982, Hill 2002, FMNH 2008). The Mayan cichlid's local range may be limited by its lower lethal temperature of 15°C (Stauffer and Boltz 1994). In contrast, the other six introduced species in the Charlotte Harbor estuary reportedly can survive temperatures of 10°C or less (Shafland and Pestrak 1982, Stauffer and Boltz 1994, Gestring et al. 2006, USGS 2008).

All the introduced fish species we collected, including those reported to inhabit brackish areas in their native ranges (African jewelfish, Mayan cichlid, and brown hoplo), appear to be restricted principally to riverine habitats in the Charlotte Harbor drainage. The reasons for their lack of success in colonizing estuarine areas are unclear. However, those with some salinity tolerance can probably use the estuary as a "saline bridge" to move between tributaries (Brown et al. 2007), particularly during periods of high precipitation and runoff.

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Caribbean Leucothoidae (Crustacea: Amphipoda) of Panama

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Recommended Citation

CARIBBEAN LEUCOTHOIDAE (CRUSTACEA: AMPHIPODA) OF PANAMA

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Abstract: Leucothoid amphipods were collected from sponge, ascidian, and bivalve mollusk hosts around Bocas del Toro, Panama. New host and locality records are reported for 10 species. Morphological variation is noted in some species originally described from Belize and South Florida. Future molecular research will help to clarify the importance of this variation. A key to the Caribbean species of the Leucothoidae collected around Bocas del Toro, Panama is provided based on morphological characters.

Key Words: *Anamixis* spp., *Leucothoe* spp., taxonomy, amphipods

Introduction

The Leucothoidae Dana, 1852 is a family of amphipods found worldwide in coral reef environments, seagrass beds, and mangrove forests. Leucothoids typically occur inside of sessile invertebrate hosts such as sponges, ascidians, and bivalve mollusks, and are frequently found in crevices in coral rubble. A long history of a problematic taxonomy confounds the use of leucothoid amphipods in applied ecological studies. The incidental collection of many species and lack of strong morphological characters used in past taxonomic analysis have led to several species being misidentified as *Leucothoe spinicarpa* Abildgaard, 1789, a situation that requires further investigation.

The species collected around Bocas del Toro, Panama are typical of the Caribbean Sea and Western Atlantic Ocean with some morphological differences from specimens previously described from Belize and South Florida. *Leucothoe garifunae* Thomas and Klebba, 2007 and *Leucothoe saron* Thomas and Klebba, 2007 are the only described Caribbean species not reported from Panama. This paper describes the leucothoid amphipods collected around Bocas del Toro, Panama and notes some morphological variation from specimens collected from Belize and South Florida.

Materials and Methods

Amphipods were collected with their hosts in June of 2009 near The Smithsonian Tropical Research Institute (STRI) in Bocas del Toro, Panama. Specimens were captured directly from their hosts using a modified squirt bottle, with their entire host in zip-lock plastic bags, or among coral rubble. Ascidian hosts were identified by Rosana Rocha (Universidade Federal do Paraná, Curitiba, Brasil). Sponge and bivalve mollusk hosts were identified using the STRI species database and literature collection unless noted in station data. Amphipods were preserved in 95% alcohol for further molecular studies. Specimens from all samples were identified to species and those selected for dissection

and illustration were transferred to glycerin. Lengths listed in descriptions represent body length of the amphipods. Morphological structures were illustrated using a drawing tube attached to a Wild M11 compound microscope and digitally inked with a Wacom® tablet following Coleman (2003). Specimens used for dissection and illustration are deposited in the Gulf Coast Research Laboratory (GCRL) Museum. All other specimens are maintained in the laboratory of the author. Diagnoses of species were generated via comparison of all species in the Leucothoidae.

Results and Discussion

Ten leucothoid species were collected on the Caribbean side of Panama near Bocas del Toro. A diagnostic description and illustrations are provided for each species. Table 1 lists host records for each leucothoid species collected in Panama, including new host records.

Ten species of leucothoid amphipods are reported from Bocas del Toro, Panama, representing new locality and host records (Table 1). With the exception of *A. vanga*, all species were reported from multiple hosts (not including species only found in coral rubble). *Leucothoe ashleyae* was collected from 9 sponge hosts (8 previously unreported); *L. barana* was collected from 6 sponge hosts (5 previously unreported); *L. flammosa* was collected from 2 bivalve mollusk hosts (one previously unreported); *L. ubouhu* was collected from 2 sponge hosts (both previously unreported); *L. wuriti* was collected from 6 ascidian hosts (5 previously unreported); and *L.* sp. C Thomas and Klebba, 2007 was collected from 2 sponge hosts (one previously unreported). Eighteen tunicates were collected, one tunicate contained one *L. wuriti* specimen, and 14 tunicates contained between 2 and 19 *L. wuriti* specimens. Thirty-three sponges were collected with 23 containing leucothoid amphipods. *Leucothoe ashleyae* was collected with *L. barana* and *L. ubouhu* in 3 sponges. Otherwise, only a single leucothoid species was collected from

TABLE 1. List of hosts recorded for each leucothoid species in Panama. A.=Anamixis; L.= Leucothoe; * = new host records; ? = could occur in both species

	A. cavatura	A. vanga	L. ashleyae	L. barana	L. kensleyi	L. flammosa	L. laurensi	L. ubouhu	L. wuriti	L. sp. C
Sponge host										
Spongia pertusa			X*	X*						
Amphimedon viridis			X*					X*		
Callyspongia vaginalis			X							
Chalinula molitba			X*							
Haliclona mucifibrosa			X*							
Haliclona (S.) twincayensis		X*								
Haliclona vansoesti								X*		
Niphates caycedoci				X*						
Niphates erecta				X						
Mycale (orange)			X*							
Mycale (white)			X*	X*						
Iotrochota birotulata			X							
Lissodendoryx columbiensis			X*	X*						
Tedania ignis										X*?
Tedania klausi										X*?
Unidentified grey chimney sponge				X*						
Bivalve Mollusk Host										
Barbatia (Cucullearca) candida						X*				
Lima scabra						X				
Ascidian Host										
Ascidia									X*	
Ascidia curvata									X*	
Ascidia sydeiensis									X*	
Phallusia nigra									X	
Rhodosoma turcicum									X*	
Herdmania pallida									X*	
Microcosmus exasperatus									X*	
Pyura									X*	
Pyura torpida									X*	
Coral Rubble	X	X		X	X		X	X		

each sponge, with colomastigid amphipods present in 4 sponges. The numbers of leucothoids ranged from one to 32 individuals per sponge. Two bivalve mollusks were collected with 2 and 5 *L. flammosa* specimens collected from each one.

Systematics

ANAMIXIS CAVATURA Thomas, 1997 (Figure 1)

Leucothoides pottsi Shoemaker, 1933, pp. 249–251, figure 3; ~ Ledoyer, 1967, p. 127, figure 5b; ~ Ruffo, 1969, p. 12–13; ~ Sivaprakasam, 1967(1969), p. 373, figures 1e-g; ~Ledoyer, 1978a, p. 375; ~ Ledoyer, 1978b, pp. 300–301; ~ Ledoyer, 1979a, p. 169; ~ Ledoyer, 1979b, p. 111, figure 68(II); ~ Thomas, 1979, pp.107–109; ~ J.L. Barnard, 1979, p. 130.

Anamixis hanseni Pearse, 1912, p. 370; ~ Thomas, 1979, pp. 107–109; ~ Thomas and Taylor, 1981, pp. 462–467, figures 1–5; ~ Thomas and Barnard, 1983, pp. 154–157 (not *Anamixis hanseni* Stebbing, 1897).

*Anamixis pottsi.* ~ Ortiz and Lemaitre, 1994, p. 124.

Anamixis cavatura Thomas, 1997, pp. 47–50, figures 3–4.

Type locality: Carrie Bow Caye, Belize, Caribbean Sea, 1–2 m.

Material examined: Two male anamorphs, 23 male and female leucomorphs; Bocas 09–13B, Hospital Point, Bocas del Toro, Panama; 0–3 m; coral rubble wash; Kristine N. White collector; 15 June 2009.

Material illustrated: One male anamorph, 4.1 mm; one female leucomorph, 3.5 mm. Bocas 09–13B. GCRL 3059.

Diagnostic description: <u>Male.</u> Head, anterodistal margin oblique with cusp; ventral cephalic keel anterior margin oblique, anterodistal margin with downward projecting cusp (Figure 1A). Gnathopod 1 coxa anterodistal corner bicuspidate; basis anterior and posterior margins bare; carpus proximal margin smooth with a single long terminal seta; propodus posterior margin with a single, long seta, palm dentate; dactylus absent (Figure 1D). Gnathopod 2 coxa slightly larger than coxae 3 and 4, anterior margin with cusp; basis anterodistally expanded with serrate ridge, anterior margin with 2 setae, posterior margin bare; carpus distally tapered, anterior margin smooth; propodus with 1 mediofacial setal row above midline, reaching less than 0.5 x propodus length, palm with 2 major tubercles; dactylus posterior proximal margin with 2 setae, 2 tubercles, and distal margin serrate (Figure 1E). Pereopods 5–7 bases broadly expanded, posterior margins setose. Epimera 1–3 bare, epimeron 3 posteroventral corner subquadrate. <u>Female.</u> Head, anterior margin truncate. Gnathopod 1 carpus with 2 terminal serrate blades; propodus palm dentate; dactylus reaching less than 0.1 x propodus length (Figure 1C). Gnathopod 2 carpus length relative to propodus length 0.5, straight, distally truncate; propodus palm sub-triangular, primary mediofacial setal row above midline; dactylus curved, posterior proximal margin smooth (Figure 1B).
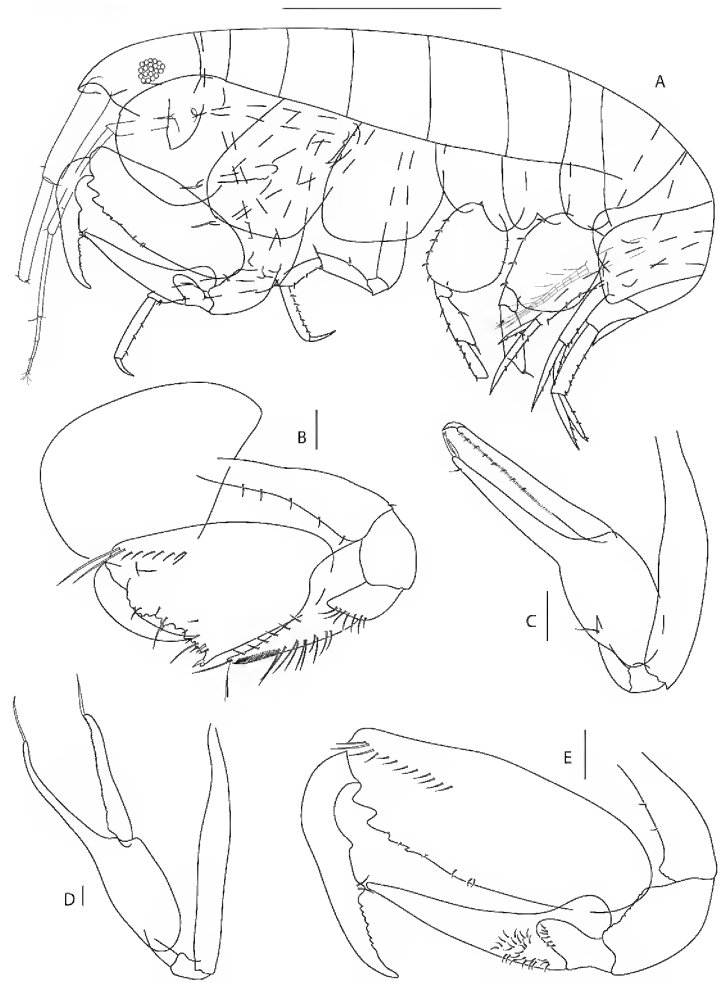
Figure 1. Anamixis cavatura *Thomas (1997). Bocas 09-13B; anamorph male, 4.1 mm; leucomorph female, 3.5 mm; GCRL 3059; all scale bars 0.1 mm unless noted. A: anamorph male, scale bar 1 mm; B: leucomorph female gnathopod 2 medial; C: leucomorph female gnathopod 1 medial; D: anamorph male gnathopod 1 medial; E: anamorph male gnathopod 2 medial.*

Remarks: Juvenile morphology dissimilar to adult males. The anamorph specimens collected in Panama differ from the original description of A. *cavatura* in the following: gnathopod 2 basis anterior margin with 2 setae (bare in the original description); and dactylus only distally serrate (entire proximal margin serrate in original description).

Distribution: Western Atlantic Ocean: Ft. Pierce Florida to Biscayne Bay, Florida Keys; Gulf of Mexico: Key West to Tampa; Caribbean Sea: Yucatan, Belize, Honduras, Jamaica, The Bahamas, Greater and Lesser Antilles, and Panama.

ANAMIXIS VANGA Thomas, 1997 (Figure 2)

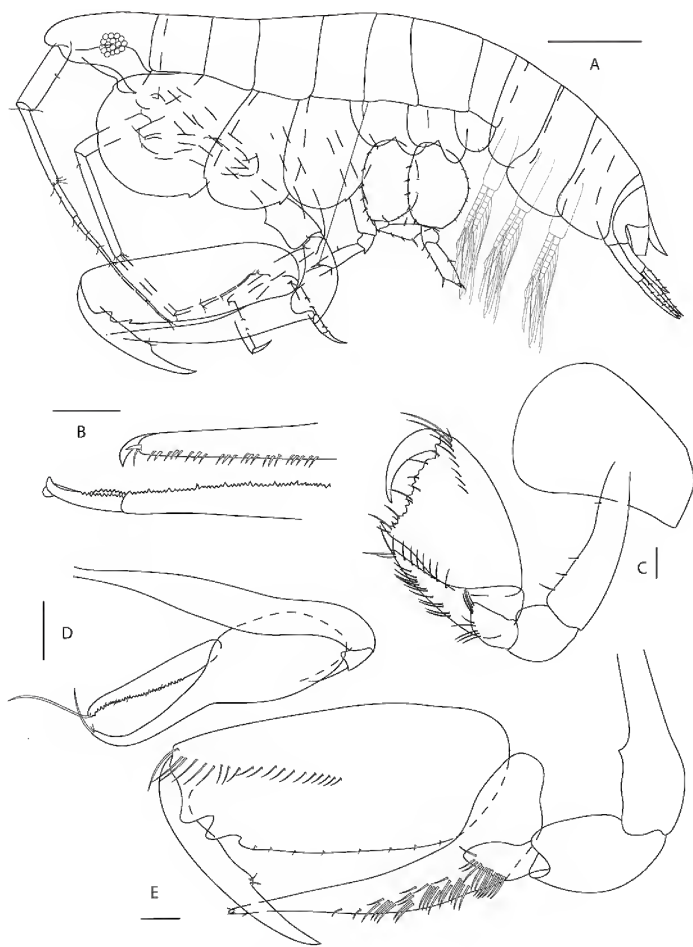*Anamixis vanga* Thomas, 1997, pp. 70–73, figures 17–18.

Type locality: Carrie Bow Cay, Belize, Caribbean Sea, 13.3 m.

Material examined: One male anamorph; Bocas 09–10A, San Cristobal, Panama; 0–2 m; coral rubble wash; Kristine N. White collector; 13 June 2009. One male anamorph, 11 male and female leucomorphs; Bocas 09–11F, Crawl Key, Panama; 1–3 m; coral rubble wash (possibly from sponge

Haliclona (S.) *twincayensis* de Weerdt et al., 1991); Kristine N. White collector; 14 June 2009.

Material illustrated: One male anamorph, 2.9 mm; one female leucomorph 3.5 mm. Bocas 09–11F. GCRL3060.

Diagnostic description: Male. Head, anterodistal margin obliquely excavate with lateral ridge; ventral cephalic keel anterior margin oblique, anterodistal margin with an anteriorly projecting cusp (Figure 2A). Gnathopod 1 carpus

Figure 2. Anamixis vanga *Thomas, 1997. Bocas 09-11F; anamorph male, 2.9 mm; leucomorph female, 3.5 mm; GCRL 3060; all scale bars 0.1 mm. A: anamorph male; B: leucomorph female, gnathopod 1 medial; C: leucomorph female gnathopod 2 medial; D: anamorph male gnathopod 1 medial; E: anamorph male gnathopod 2 medial.*

proximal margin smooth, with long terminal seta; propodus posterior margin with a single, long seta, palm serrate with proximal setae; dactylus absent (Figure 2D). Gnathopod 2 coxa anterior and posterior margins with a single distal cusp; basis with slight anterodistal tubercle, bare; carpus length relative to propodus length 0.8, distally tapered; propodus with 1 mediofacial setal row displaced to midline, reaching between 0.5 and 0.7 x propodus length, palm linear with 3 major tubercles; dactylus proximal margin with

one tubercle and two setae (Figure 2E). Pereopods 5–7 bases narrowly expanded, posterior margins serrate, setose. Epimera 1–3 bare; epimeron 3 posteroventral corner subquadrate. Female. Head, anterior margin rounded. Gnathopod 1 carpus length 7 x width, proximal margin dentate with terminal spines, palm dentate, dactylus smooth, reaching less than 0.1 x propodus length (Figure 2B). Gnathopod 2 carpus length relative to propodus length 0.4, straight, distally truncate; propodus posterior margin smooth, primary mediofacial setal row above midline, palm sub-rectangular; dactylus curved, proximal margin smooth (Figure 2C).

Remarks: Juvenile morphology dissimilar to adult males. Leucomorphs agree closely with Thomas (1997). Anamorphs collected in Panama were yellowish in color, with white spots on coxae. Leucomorphs transparent, no color. Anamorph male specimens of A. *vanga* collected in Panama differ from those of Thomas (1997) in the following: habitus with yellow coloration (pink in original description); gnathopod 2 basis with slight anterodistal tubercle (smooth in original description), propodus without submarginal seta (1 seta in original description); pereopod 4 coxa distally rounded (slightly excavate in original description); and pereopods 5–7 posterior margins rounded (slightly excavate in original description).

*Distribution*: Western Atlantic Ocean: Georgia to the Florida Keys; Caribbean Sea: Belize, Panama.

LEUCOTHOE ASHLEYAE Thomas and Klebba, 2006 (Figure 3)
   Leucothoe ashleyae Thomas and Klebba, 2006 pp.14–16, figures 1–3.

Type locality: Whale Shoals, Belize, Central America, Caribbean Sea, 1–20 m.

Material examined: Two males, Bocas 09–5A, Punta Caracol, Panama; 0–3 m; in sponge *Lissodendoryx columbiensis* Zea and van Soest, 1986; Kristin Hultgren collector; 9 June 2009. Five males and 8 females, Bocas 09–6A, Punta Caracol, Panama; 0–3 m; in sponge *Iothrochota birotulata* (Higgin, 1877); Kristin Hultgren collector; 10 June 2009. Thirteen males and 7 females, Bocas 09–6E, Punta Caracol, Panama; 0–3 m; in sponge *Mycale* of Gray, 1867; Kristin Hultgren collector; 10 June 2009. One male, Bocas 09–7D, The Gardens, Panama; 15 m; in sponge *Mycale* of Gray, 1867; Kristine N. White collector; 11 June 2009. Two females, Bocas 09–7E, Solarte, Panama; 10 m; in sponge *Amphimedon viridis* Duchassaing and Michelotti, 1864; Kristine N. White collector; 11 June 2009. Fifteen males and 19 females, Bocas 09–8F, J, K, mangroves and seagrass between and STRI dock and STRI point, Bocas del Toro, Panama; 1–3 m; in sponges *Haliclona mucifibrosa* de Weerdt et al., 1991, *Callyspongia vaginalis* Lamarck, 1814, and *Lissodendoryx columbiensis*, 1986; Kristine N. White collector; 12 June 2009. Five males and 10 females, Bocas 09–9A-B, Los Pastores, Panama; 1–4 m; in sponges *Spongia pertusa* Hyatt, 1877 and *Iotrochota birot-*
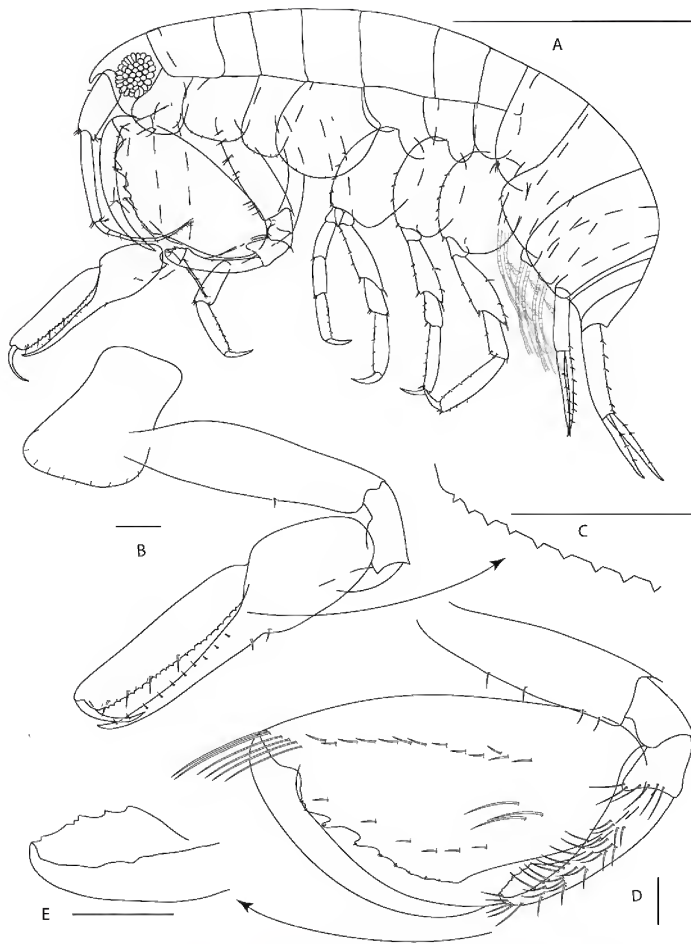
Figure 3. Leucothoe ashleyae *Thomas and Klebba, 2006.*
Bocas 09-8F; male, 3.3 mm; female, 3.6 mm; GCRL 3061; all scale bars 0.1 mm unless noted. A: male, scale bar 1 mm; B: male gnathopod 1 medial; C: male gnathopod 1 propodus palm magnified; D: male gnathopod 2 medial; E: male gnathopod 2 carpus magnified.

ulata (Higgin, 1877); Kristine N. White collector; 13 June 2009.

Material illustrated: One male, 3.3 mm; one female 3.6 mm. Bocas 09-8F. GCRL 3061.

Diagnostic description: <u>Male.</u> Head, anterodistal margin evenly rounded; ventral cephalic keel anteroventral margin rounded, ventral margin excavate (Figure 3A). Gnathopod 1 coxa distal margin setose; basis anterior margin with 1 seta, posterior margin bare; carpus proximal margin dentate; propodus palm serrate (Figure 3C) with 4 proximal setae; dactylus reaching greater than 0.2 x propodus length (Figure 3B). Gnathopod 2 coxa distal margin setose; basis anterior margin with 6 setae, posterior margin bare; carpus distally expanded, anterior margin dentate (Figure 3E); propodus with 2 mediofacial setal rows, primary mediofacial setal row above midline, reaching between 0.5 and 0.7 x propodus length, secondary mediofacial setal row with 3 setae, with submarginal setae, palm with 3 major tubercles (Figure 3D). Pereopods 3-4 coxae distal margins setose. Pereopods 5-7

bases broadly expanded. Epimeron 1 with tuft of antero-ventral setae, epimeron 2 with ventral setae, epimeron 3 posteroventral corner subquadrate. <u>Female.</u> Gnathopod 2 propodus palm with slightly smaller tubercles.

Remarks: Male specimens of *L. ashleyae* Thomas and Klebba, 2006 collected in Panama differ from the original description in the following characters: gnathopod 1 coxa anterodistal corner smooth, carpus with distal setae (bare in original description); gnathopod 2 coxa distal margin setose, propodus with longer setae in secondary mediofacial row and submarginal setal row than in original description, secondary mediofacial setal row with 3 setae (2 in original description); coxae 3-4 distal margins setose; pereopods 5-7 bases posterior margin smooth and bare (serrate and setose in original description); and uropods with variations in number of robust setae.

Distribution: Western Atlantic Ocean: Southeast Florida, Florida Keys; Caribbean Sea: Belize, Roatan, Bahamas, Vieques, Puerto Rico, Panama.

LEUCOTHOE BARANA Thomas and Klebba, 2007 (Figure 4)
Leucothoe barana Thomas and Klebba, 2007, pp. 5-10, figures 1-3.

Type locality: Co Cat Cay, Pelican Cays, Belize, Caribbean Sea, 1-15 m.

Material examined: Two males, one female, Bocas 09-5A, Punta Caracol, Panama; 0-3 m; in sponge *Lissodendoryx columbiensis*; Kristin Hultgren collector; 9 June 2009. Two females, Bocas 09-6D, F, Punta Caracol, Panama; 0-3 m; in sponges *Spongia pertusa* and *Niphates caycedoci* Zea and van Soest, 1986; Kristin Hultgren collector; 10 June 2009. One male and one female, Bocas 09-7E, The Gardens, Panama; 15 m; in sponge *Mycale*; Kristine N. White collector; 11 June 2009. One female, Bocas 09-7C, Solarte, Panama; 10 m; in unidentified grey chimney sponge; Kristine N. White collector; 11 June 2009. Four males and 2 females, Bocas 09-8H, mangroves and seagrass between and STRI dock and STRI point, Bocas del Toro, Panama; 1-3 m; in sponge *Niphates erecta* Duchassaing and Michelotti, 1864; Kristine N. White collector; 12 June 2009. One male and 1 female, Bocas 09-11G, Crawl Key, Panama; 1-4 m; coral rubble wash; Kristine N. White collector; 14 June 2009. One male, Bocas 09-12B, Hospital Point, Panama; 0-2 m; in sponge *Lissodendoryx columbiensis*; Kristin Hultgren collector; 14 June 2009;

Material illustrated: One male, 6.9 mm; one female 7.0 mm. Bocas 09-8H. GCRL 3062.

Diagnostic description: <u>Male.</u> Head, anterodistal margin quadrate, with cusp; ventral cephalic keel anteroventral margin with anteriorly projecting cusp (Figure 4A). Gnathopod 1 coxa anterodistally serrate; basis anterior margin with 1-10 setae, posterior margin with 2 setae; carpus proximal margin serrate, propodus palm dentate with six distal setae; dactylus

Figure 4. Leucothoe barana *Thomas and Klebba, 2007. Bocas 09-8H; male, 6.9 mm; female, 7.0 mm; GCRL 3062; all scale bars 0.1 mm unless noted. A: male, scale bar 1 mm; B: male gnathopod 2 medial; C: male gnathopod 1 medial; D: female gnathopod 2 medial.*

reaching greater than 0.2 x propodus length (Figure 4C). Gnathopod 2 coxa distal margin anteriorly and posteriorly serrate; basis anterior margin with 12–16 setae, posterior margin bare; carpus distally truncate, anterior margin dentate; propodus with 2 mediofacial setal rows, primary mediofacial setal row above midline, reaching greater than 0.7 x propodus length, secondary mediofacial setal row with 4 setae, palm with 3 major tubercles; dactylus curved, reaching 0.5–0.7 x propodus length (Figure 4B). Pereopod 3 coxa anteriorly and posterodistal margin serrate. Pereopod 4 coxa distal margin anteriorly and posteriorly serrate. Pereopods 5–7 bases narrowly expanded, posterior margins serrate. Epimera 1–2 with ventral setae, epimeron 3 posteroventral corner narrowly rounded. Female. Gnathopod 2 propodus palm with smaller tubercles, secondary mediofacial row with 8 setae (Figure 4D).

Remarks: Male specimens of *L. barana* collected in Panama differ from the original description of this species by Thomas and Klebba (2007) in the following: gnathopod 1 basis with 2 posterior setae and lacking distal setae on the carpus; gnathopod 2 basis with fewer anterior and posterior setae, propodus with fewer setae in the secondary mediofacial se-

tal row (8 in original description); pereopod 3 coxa less serrate; and epimeron 1 with ventral setae.

Distribution: Western Atlantic Ocean: Florida Keys; Caribbean Sea: Belize, Panama.

    Leucothoe flammosa Thomas and Klebba, 2007 (Figure 5)
   *Leucothoe spinicarpa.* ~ Ortiz, 1975, p. 8.
    Leucothoe flammosa Thomas and Klebba, 2007, pp. 10–15, figures 4–6.

Type locality: Key West, Florida, U.S.A., Western Atlantic Ocean, 1–3 m.

Material examined: Three males and 4 females, Bocas 09-8A–B, mangroves and seagrass between and STRI dock and STRI point, Bocas del Toro, Panama; 1–3 m; in bivalve mollusks *Lima scabra* Born, 1778 and *Barbatia* (*Cucullearca*) *candida* (Helbling, 1779) (ID by Amy Moran, Clemson University, South Carolina); Kristine N. White collector; 12 June 2009.

Material illustrated: One male, 3.8 mm; one female 3.2 mm. Bocas 09-8B. GCRL 3063.

Diagnostic description: <u>Male</u>. Head, anterodistal margin even-
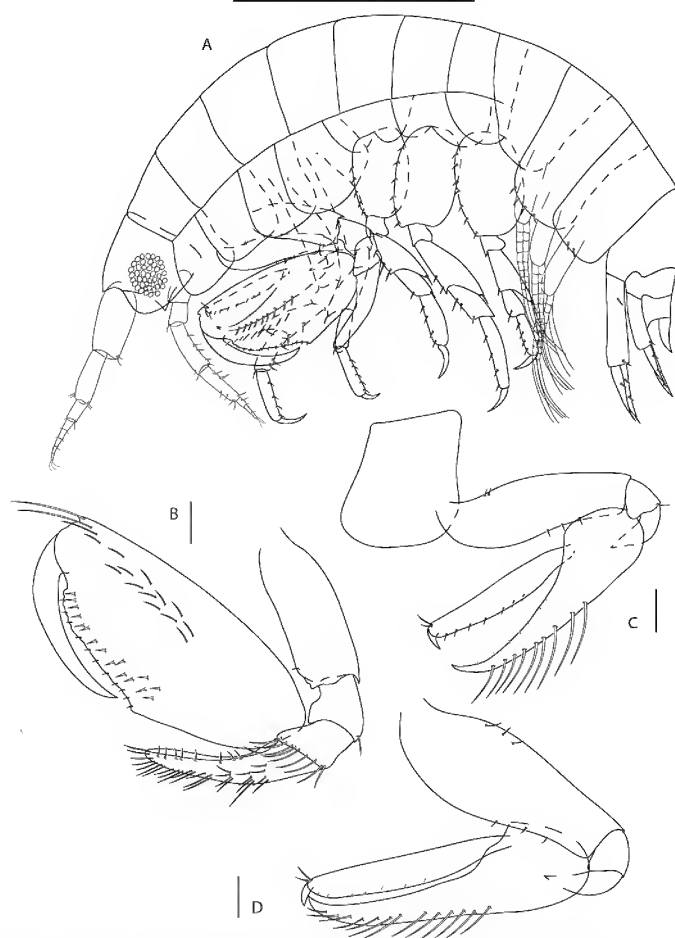
Figure 5. Leucothoe flammosa *Thomas and Klebba, 2007. Bocas 09-8B; male, 3.8 mm; female, 3.2 mm; GCRL 3063; all scale bars 0.1 mm unless noted. A: male, scale bar 1 mm; B: male gnathopod 2 medial; C: male gnathopod 1 medial; D: female gnathopod 1 medial.*

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ly rounded; ventral cephalic keel anterior margin excavate, anteroventral margin with simple cusp (Figure 5A). Gnathopod 1 basis proximally widened, anterior margin with 3 setae, posterior margin bare; carpus distal margin with several long setae; propodus palm smooth with 7 distal setae; dactylus reaching 0.1–0.2 x propodus length (Figure 5C). Gnathopod 2 basis anterior margin with 2 setae, posterior margin bare; carpus distally tapered, anterior margin dentate; propodus with 1 mediofacial setal row above midline, reaching between 0.5 and 0.7 x propodus length, with field of submarginal setae, palm with 6 small tubercles (Figure 5B). Pereopods 5–7 bases narrowly expanded. Uropod 1 peduncle with proximal seta. Epimera 1–3 with ventral setae, epimeron 3 posteroventral corner subquadrate. Female. Gnathopod 1 carpus with shorter distal setae (Figure 5D).

Remarks: Male specimens of *L. flammosa* collected in Panama differ from the original description of this species by Thomas and Klebba (2007) in the following: gnathopod 1 carpus with fewer, shorter distal setae; gnathopod 2 basis with fewer anterior setae, propodus mediofacial and submarginal setae less dense.

Distribution: Western Atlantic Ocean: Florida; Caribbean Sea: Belize, Panama.

LEUCOTHOE KENSLEYI Thomas and Klebba, 2006 (Figure 6)
*Leucothoe tridens* J.L. Barnard, 1965, p. 492; ~ J.L. Barnard, 1970, p. 211, figure 137; ~ J.L. Barnard, 1971, p.103.
Leucothoe kensleyi Thomas and Klebba, 2006, pp. 17–22, figures 4–6.

Type locality: Ft. Lauderdale, Florida, U.S.A, Western Atlantic Ocean, 1–20 m.

Material examined: One female, Bocas 09–8C, mangroves and seagrass between and STRI dock and STRI point, Bocas del Toro, Panama; 1–3 m; in sponge *Chalinula molitba* (de Laubenfels, 1949); Kristine N. White collector; 12 June 2009. One male, 2 females, Bocas 09–11A, Crawl Key, Bocas del Toro, Panama; 1–3 m; coral rubble with calcareous green alga *Halimeda* of Lamouroux (1812) and red alga *Gracilaria* of Greville, 1830; Kristine N. White collector; 14 June 2009.

Material illustrated: One male, 3.4 mm; one female 3.2 mm. Bocas 09–11A. GCRL 3064.

Diagnostic description: Male. Head, anterior margin truncate, anterodistal margin quadrate with cusp; ventral cephalic keel anteroventral margin with simple cusp (Figure 6A). Gnathopod 1 coxa with anterodistal cusp; basis anterior margin with 2 setae, posterior margin bare; carpus proximal margin smooth, with distal seta; propodus palm dentate with 3 distal setae; dactylus reaching greater than 0.2 x propodus length (Figure 6C). Gnathopod 2 coxa margins subacute; basis anterior margin with 5 setae, posterior margin bare; carpus distally tapered, anterior margin dentate; propodus
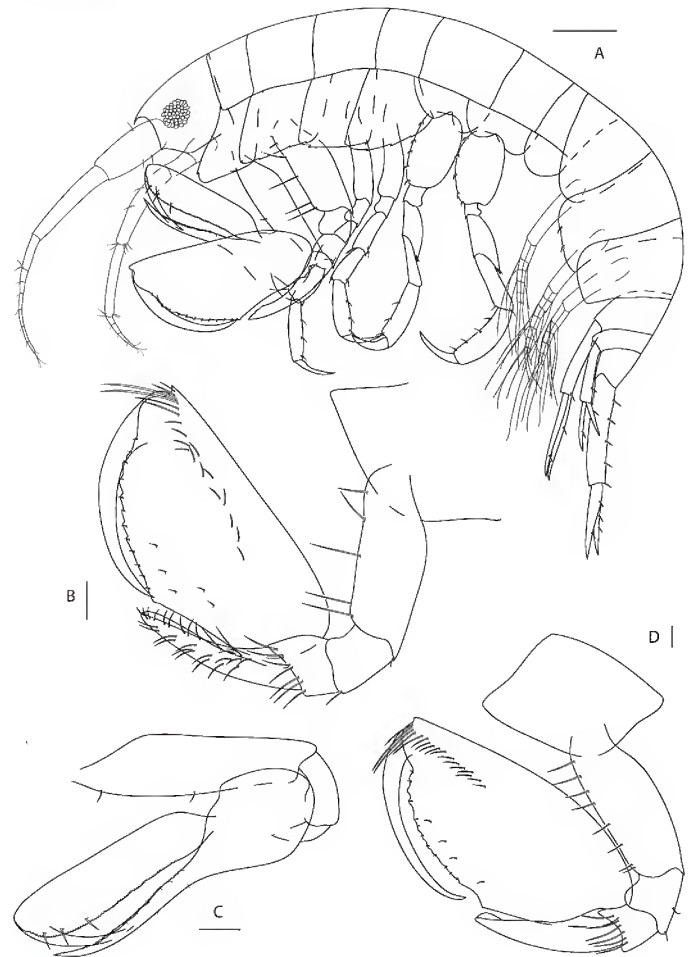

Figure 6. Leucothoe kensleyi *Thomas and Klebba, 2006. Bocas 09-11A; male, 3.4 mm; female, 3.2 mm; GCRL 3064; all scale bars 0.1 mm. A: male; B: male gnathopod 2 medial; C: male gnathopod 1 medial; D: female gnathopod 2 medial.*

with 2 mediofacial setal rows, primary mediofacial setal row above midline, reaching between 0.5 and 0.7 x propodus length, secondary mediofacial setal row with 2 setae, palm with small tubercles (Figure 6B). Pereopod 3–4 coxae distal margins serrate. Pereopods 5–7 bases narrowly expanded, pereopods 5 and 7 posterior margins setose. Epimeron 2 ventral margin setose; epimeron 3 posteroventral corner subquadrate. Female. Gnathopod 2 with 1 mediofacial setal row reaching between 0.4 and 0.5 x propodus length (Figure 6D).

Remarks: Male specimens of *L. kensleyi* collected in Panama differ from the original description of this species by Thomas and Klebba (2006) in the following: gnathopod 1 carpus with distal seta and propodus with one less distal seta; gnathopod 2 basis with fewer anterior setae, propodus with fewer setae in the secondary mediofacial row and submarginal setal row. Females differ in having a shorter mediofacial setal row.

Distribution: Western Atlantic Ocean: South Florida, Florida
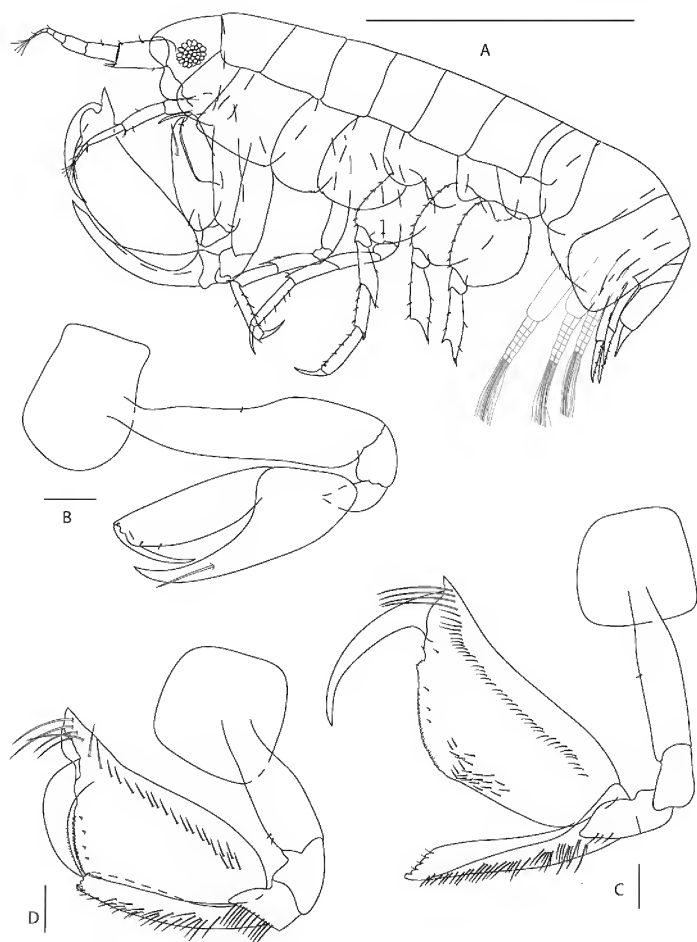
Figure 7. Leucothoe laurensi *Thomas and Ortiz, 1995. Bocas 09-11D; male, 3.7 mm; female, 2.4 mm; GCRL 3065; all scale bars 0.1 mm unless noted. A: male, scale bar 1 mm; B: male gnathopod 1 medial; C: male gnathopod 2 medial; D: female gnathopod 2 medial.*

Keys; Caribbean Sea: Belize, Panama; Brazil: Bahia; Pacific: Hawaii, Oahu.

LEUCOTHOE LAURENSI Thomas and Ortiz, 1995 (Figure 7)
Leucothoe laurensi Thomas and Ortiz, 1995, pp. 613–616, figures 1–2; ~ Serejo, 1998 pp. 117–119, figure 8.

Type locality: Punta Pedernales, Isla de la Juventud, Cuba, 50 m.

Material examined: One male, Bocas 09–10B, San Cristobal, Panama; 0–2 m; coral rubble covered with zooanthids; Kristine N. White collector; 13 June 2009. Six males and 8 females, Bocas 09–11D, Crawl Key, Bocas del Toro, Panama; 1–3 m; coral rubble with calcareous green alga *Halimeda* and red alga *Gracilaria*; Kristine N. White collector; 14 June 2009.

Material illustrated: One male, 3.7 mm; one female 2.4 mm. Bocas 09–11D. GCRL 3065.

Diagnostic description: Male. Head, anterior margin with cusp; ventral cephalic keel anteroventrally rounded (Figure 7A). Gnathopod 1 coxa anterodistally rounded; basis

distally expanded, anterior margin bare, posterior margin with single seta; carpus proximal margin smooth with long distal seta; propodus palm smooth with 2 distal setae; dactylus reaching greater than 0.2 x propodus length (Figure 7B). Gnathopod 2 basis anterior margin with 1 seta; posterior margin bare; carpus length relative to propodus length 0.7, distally truncate, anteriorly dentate; propodus distal margin with blade-like process, with 1 mediofacial setal row above midline, reaching greater than 0.7 x propodus length, with field of submarginal setae, palm sub–rectangular, with one large tubercle; dactylus curved, proximal margin bare (Figure 7C). Pereopod 3 coxa distal margin serrate. Pereopod 4 coxa anterodistal margin serrate. Pereopods 5–7 bases broadly expanded. Pereopod 7 basis posterior margin serrate. Epimera 1–3 with ventral setae; epimeron 3 posteroventral corner rounded. Female. Gnathopod 2 carpus slightly less truncate than found in male, propodus with larger distal blade-like process, more triangular, palm smooth with embedded truncate spines, dactylus proximal margin dentate (Figure 7D).

Remarks: Male specimens of *L. laurensi* were not drawn in the original description of this species by Thomas and Ortiz (1995). Female specimens collected in Panama differ in the absence of a secondary mediofacial setal row on the gnathopod 2 propodus (1 seta in original description).

Distribution: Western Atlantic Ocean: Florida Keys, Cuba, Brazil (Pernambuco, Alagoas); Caribbean Sea, Panama.

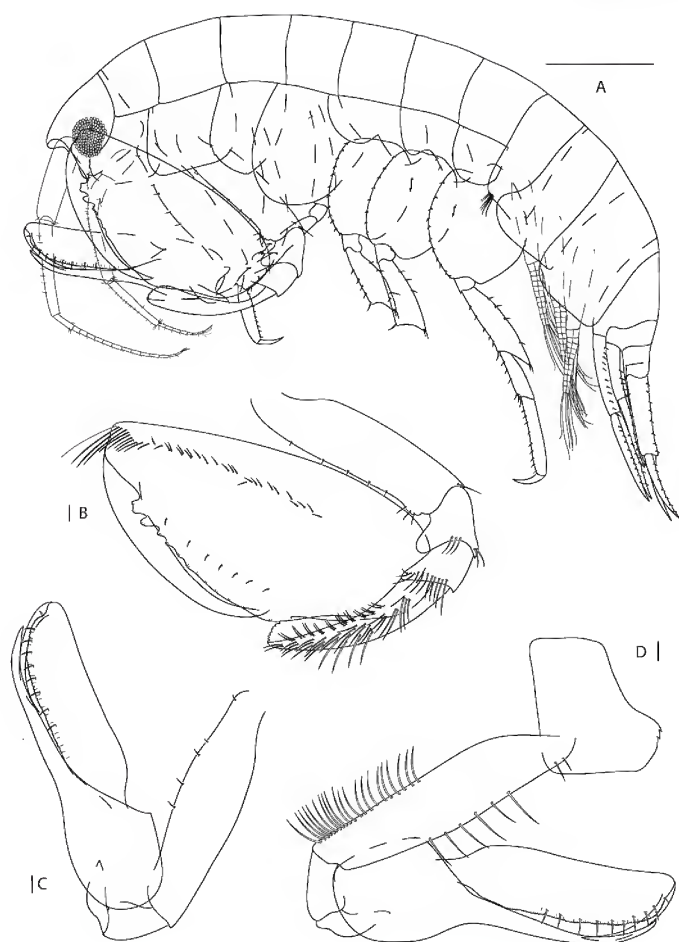LEUCOTHOE UBOUHU Thomas and Klebba, 2007 (Figure 8)
Leucothoe ubouhu Thomas and Klebba, 2007, pp. 25–30, figures 15–18.

Type locality: Co Cat Cay, Pelican Cays, Belize, Caribbean Sea, 1–15 m.

Material examined: Two females, Bocas 09–7D; Solarte, Sachem, Panama; 10 m; in *Amphimedon viridis*; Kristine N. White collector; 11 June 2009. One male and one female, Bocas 09–11H, Crawl Key, Bocas del Toro, Panama; 1–3 m; in *Haliclona vansoesti* de Weerdt et al., 1999; Kristine N. White collector; 14 June 2009.

Material illustrated: One male, 6.2 mm; one female 7.4 mm. Bocas 09–11H. GCRL 3066.

Diagnostic description: Male. Head, anterior margin truncate, anterodistal margin with cusp; ventral cephalic keel anterior margin transverse, anteroventral margin rounded (Figure 8A). Gnathopod 1 coxa with anterodistal cusp; basis anterior margin with 5 setae, posterior margin bare; carpus proximal margin dentate; propodus palm dentate with 9 distal setae; dactylus reaching greater than 0.2 x propodus length (Figure 8C). Gnathopod 2 basis anterior margin with 8 setae, posterior margin bare; carpus distally truncate, anterior margin dentate; propodus with 1 mediofacial setal row above midline, reaching between 0.5 and 0.7 x propodus length, with 1 row of submarginal setae, palm with 2

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Figure 8. Leucothoe ubouhu *Thomas and Klebba, 2007. Bocas 09-11H; male, 6.2 mm; female, 7.4 mm; GCRL 3066; all scale bars 0.1 mm unless noted. A: male, scale bar 1 mm; B: male gnathopod 2 medial; C: male gnathopod 1 medial; D: female gnathopod 1 medial.*

major tubercles (Figure 8B). Pereopod 3 coxa distal margin anteriorly serrate. Pereopods 5-7 bases broadly expanded, posterior margins serrate. Epimeron 1 with tuft of ventral setae, epimeron 2 bare, epimeron 3 posteroventral corner rounded. <u>Female</u>. Gnathopod 1 basis posterior margin with 21 long setae and propodus with 10 distal setae (Figure 8D).

Remarks: Male specimens of *L. ubouhu* collected in Panama differ from the original description of this species by Thomas and Klebba (2007) in the following: gnathopod 2 propodus with 1 mediofacial setal row (secondary row of 4 setae in original description); pereopod 3 coxa with distal serrations; epimeron 1 with a tuft of setae (bare in the original description), and epimeron 2 bare (with 4 ventral setae in original description). Females differ in the higher number of posterior setae on the basis of gnathopod 1 and the 10 distal setae on the propodus (9 in the original description).

*Distribution:* Western Atlantic Ocean: Florida; Caribbean Sea: Belize, Panama.

LEUCOTHOE WURITI Thomas and Klebba, 2007 (Figure 9)

Leucothoe spinicarpa Ortiz, 1975, p. 10, figure 5.

Leucothoe wuriti Thomas and Klebba, 2007, pp. 30-35, figures 19-21.

Type locality: Co Cat Cay, Pelican Cays, Belize, Caribbean Sea, 2-15 m.

Material examined: One male, one female, Bocas 09-01A, Bocas City, Panama; in ascidian *Pyura torpida* (Sluiter, 1898); Rosana Rocha collector; 2 August 2008. Four males, 4 females, Bocas 09-01B, STRI dock, Bocas del Toro, Panama; in ascidian *Microcosmus exasperatus* Heller, 1878; Rosana Rocha collector; 3 August 2008. Seven males, 12 females, Bocas 09-01C, Marina Bocas, Bocas del Toro, Panama; in ascidian *Ascidia* of Linnaeus, 1767; Rosana Rocha collector; 3 May 2009. Two males, 4 females, Bocas 09-02A-C, Big Bight, Panama; in ascidians *Microcosmus exasperatus*, *Herdmania pallida* (Heller, 1878), and *Ascidia sydeiensis* Stimpson, 1855; Rosana Rocha's tunicate class collector; 5 June 2009. Two males, 2 females, Bocas 09-02E-F, Marina Bocas, Panama; in ascidians *Ascidia curvata* (Traustedt, 1882) and *Phallusia*
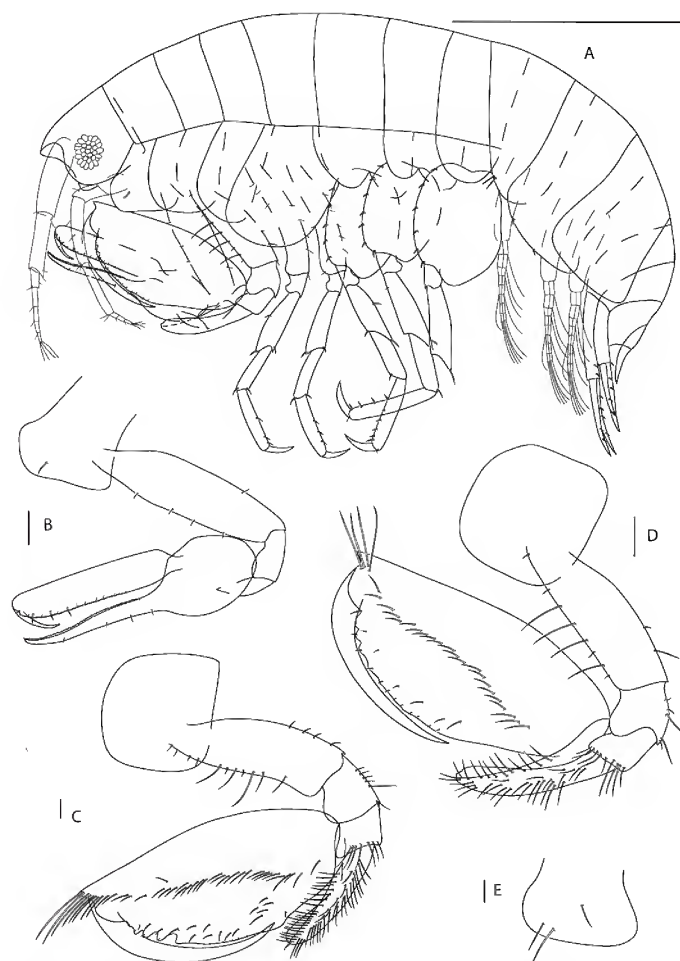
Figure 9. Leucothoe wuriti *Thomas and Klebba, 2007. Bocas 09-01C; male, 3.8 mm; female, 6.2 mm; GCRL 3067; all scale bars 0.1 mm unless noted. A: male, scale bar 1 mm; B: male gnathopod 1 medial; C: female gnathopod 2 medial; D: male gnathopod 2 medial; E: female coxa 1 medial.*

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nigra; Rosana Rocha's tunicate class collector; 5 June 2009. Three males, 7 females, Bocas 09–03A–B, Big Bight, Panama; in ascidians *Pyura* and *Ascidia sydeiensis*; Rosana Rocha's tunicate class collector; 6 June 2009. One male, 1 female, Bocas 09–04A, Jolarte, Panama; in ascidian *Herdmania pallida*; Rosana Rocha's tunicate class collector; 7 June 2009. One female, Bocas 09–04B, Isla Cristobal, Panama; in ascidian *Rhodosoma turcicum* (Savigny, 1816); Rosana Rocha's tunicate class collector; 7 June 2009. Two males, 4 females, Bocas 09–08G, mangroves and seagrass between and STRI dock and STRI point, Bocas del Toro, Panama; 1–3 m; in ascidian *Phallusia nigra*; Kristine N. White collector; 12 June 2009.

Material illustrated: One male, 3.8 mm; one female, 6.2 mm. Bocas 09–01C. GCRL 3067.

Diagnostic description: <u>Male</u>. Head, anterodistal margin evenly rounded; ventral cephalic keel anterior margin excavate, anteroventral margin with simple cusp (Figure 9A). Gnathopod 1 coxa with single facial seta on medial surface; basis anterior margin with 4 setae, posterior margin with single short seta; carpus proximal margin dentate; propodus palm dentate with 3 distal setae; dactylus reaching greater than 0.2 x propodus length (Figure 9B). Gnathopod 2 basis anterior margin with 8 setae, posterior margin with 2 setae; carpus distally truncate, anterior margin dentate; propodus with 1 mediofacial setal row displaced to midline, reaching greater than 0.7 x propodus length, with submarginal setae, palm with 3 major tubercles (Figure 9D). Pereopods 5–7 bases narrowly expanded, posterior margins bare. Epimera 1 and 2 each with 2 ventral setae, epimeron 3 posteroventral corner subquadrate, slightly produced. <u>Female</u>. Gnathopod 1 coxa with 3 facial setae on medial surface (Figure 9E); gnathopod 2 more setose overall (Figure 9C).

Remarks: Male specimens of *L. wuriti* collected in Panama differ from the original description of this species by Thomas and Klebba (2007) in the following: antenna 1 with fewer setae; gnathopod 1 coxa with shorter facial seta, propodus palm with fewer distal setae (5 in the original description); gnathopod 2 propodus palm with smaller projections and fewer submarginal setae; epimeron 1 with two ventral setae (bare in original description), and epimeron 2 with only 2 ventral setae (4 in original description). The male used in this diagnosis is much smaller than the female examined here and the male in the original description, which may explain the less developed structures described here, particularly the more setose condition found in the female.

Distribution: Western Atlantic Ocean: Florida; Caribbean Sea: Belize, Panama.

Leucothoe SP. C Thomas and Klebba, 2007 (Figure 10)
   Leucothoe n. sp. C Thomas and Klebba, 2007, p. 41, figure 25c.

Material examined and illustrated: One male, 4.9 mm; one female 4.5 mm. Bocas 09–11I, Crawl Key, Bocas del Toro, Panama; 1–3 m; in sponge *Tedania ignis* Duchassaing and Michelotti, 1864 (possibly *Tedania klausi* Wulff, 2006); Kristine N. White collector; 14 June 2009; GCRL 3068.

Diagnostic description: <u>Male</u>. Head, anterodistal margin evenly rounded; ventral cephalic keel anteroventral margin rounded (Figure 10A). Gnathopod 1 basis anterior margin with 4 setae, posterior margin bare; carpus proximal margin dentate; propodus palm dentate with 6 distal setae; dactylus reaching greater than 0.2 x propodus length (Figure 10E). Gnathopod 2 basis anterior margin with 6 setae, posterior margin bare; carpus distally rounded, expanded, anterior margin dentate (Figure 10C); propodus with 2 mediofacial setal rows, primary mediofacial row above midline, reaching greater than 0.7 x propodus length, secondary mediofacial row with 1 seta, palm with 3 major tubercles (Figures 10B). Pereopods 5–7 bases broadly expanded, posterior margins setose. Epimeron 2 with 2 ventral setae, epimeron 3 posteroventral corner subquadrate, slightly produced. <u>Female</u>.
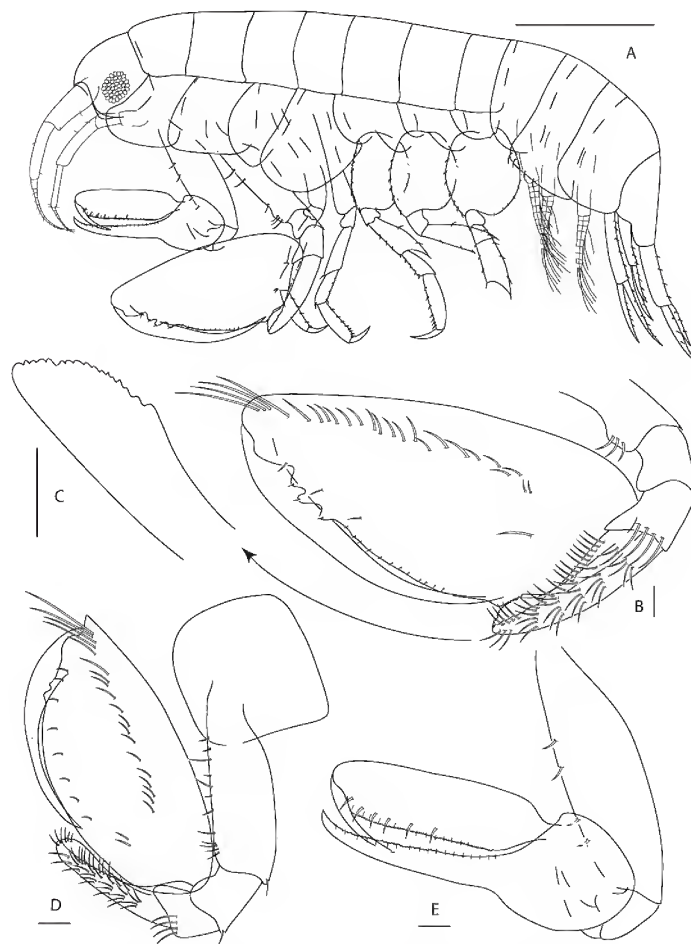
Figure 10. Leucothoe *sp. C Thomas and Klebba, 2007. Bocas 09-11I; male, 4.9 mm; female, 4.5 mm; GCRL 3068; all scale bars 0.1 mm unless noted. A: male, scale bar 1 mm; B: male gnathopod 2 medial; C: male gnathopod 2 carpus lateral; D: female gnathopod 2 medial; E: male gnathopod 1 medial.*

Gnathopod 2 basis anterior margin with 12 setae; carpus less expanded distally; propodus secondary mediofacial setal row with 2 setae, and palm projections smaller than in male (Figure 10D).

Remarks: Male specimens of *Leucothoe* sp. collected in Panama differ from the original remarks of *Leucothoe* n. sp. C in Thomas and Klebba (2007) in the following: gnathopod 1 basis with fewer setae on anterior margin (11 setae in Thomas and Klebba 2007), propodus palm with 6 distal setae (5 in Thomas and Klebba 2007); gnathopod 2 propodus with shorter secondary mediofacial setal row (8 setae in Thomas and Klebba 2007). Due to the morphological differences noted between specimens, this species will continue to be referred to as *Leucothoe* sp. C pending further analyses and comparison to material from Florida and Belize.

Distribution: Western Atlantic Ocean: Florida; Caribbean Sea: Belize, Panama.

Key to Caribbean Leucothoid species of Panama

1. Extreme sexual dimorphism; coxa 1 reduced; mouthparts reduced in adult males 2

    Moderate to no sexual dimorphism; coxae 1–4 relatively equal in widths; mouthparts well developed 3

2. Head anterior margin rounded, anterodistal margin with cusp, without lateral ridge; gnathopod 1 propodus palm dentate; gnathopod 2 basis with serrate ridge, primary mediofacial setal row above midline, dactylus proximal margin with 2 tubercles, serrate .... *Anamixis cavatura*

    Head anterior margin excavate, anterodistal margin without cusp, with lateral ridge; gnathopod 1 propodus palm serrate; gnathopod 2 basis without small tubercle, primary mediofacial setal row displaced to midline, dactylus proximal margin with 1 tubercle, smooth .... *Anamixis vanga*

3. Gnathopod 1 basis anterior margin bare; gnathopod 2 carpus reaching greater than 0.6 x propodus length, anterior margin smooth, propodus subrectangular, distal margin with blade-like process............*Leucothoe laurensi*

    Gnathopod 1 basis anterior margin setose; gnathopod 2 carpus reaching less than 0.6 x propodus length, an-

terior margin with ornamentation, propodus convex, distal margin broadly rounded 4

4. Gnathopod 1 carpus with long distal setae, propodus palm smooth, dactylus reaching 0.1–0.2 x propodus length .... *Leucothoe flammosa*

    Gnathopod 1 carpus without long distal setae, propodus palm with ornamentation, dactylus reaching greater than 0.2 x propodus length 5

5. Gnathopod 1 coxa with medial facial seta(e), gnathopod 2 propodus mediofacial setal row displaced to midline .... *Leucothoe wuriti*

    Gnathopod 1 coxa without medial facial seta(e), gnathopod 2 propodus mediofacial setal row above midline 6

6. Gnathopod 1 propodus palm serrate .... *Leucothoe ashleyae*

    Gnathopod 1 propodus palm dentate 7

7. Head rounded, anterodistal margin without cusp ....*Leucothoe* sp. C Thomas and Klebba, 2007

    Head truncate , anterodistal margin with cusp 8

8. Gnathopod 1 carpus proximal margin smooth, gnathopod 2 carpus distally tapered .... *Leucothoe kensleyi*

    Gnathopod 1 carpus proximal margin dentate, gnathopod 2 carpus distally truncate...................................... 9

9. Gnathopod 1 basis posterior margin bare, pereopods 5–7 bases narrowly expanded .... *Leucothoe barana*

    Gnathopod 1 basis posterior margin setose, pereopods 5–7 bases broadly expanded .... *Leucothoe ubouhu*

Conclusions

The slight intraspecific morphological variation between some specimens collected in Panama and other parts of the Caribbean Sea or Western Atlantic Ocean suggest that cryptic speciation may be occurring as documented in *Leucothoe ashleyae* (Richards et al. 2006). This variation is more than the author has personally observed in previous material examined from the Caribbean. Future molecular research will help to clarify whether this is cryptic speciation or simply intraspecific variation as well as evolutionary relationships between species.

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Trade-offs Between Gear Selectivity and Logistics when Sampling Nekton from Shallow Open Water Habitats: A Gear Comparison Study

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TRADE-OFFS BETWEEN GEAR SELECTIVITY AND LOGISTICS WHEN SAMPLING NEKTON FROM SHALLOW OPEN WATER HABITATS: A GEAR COMPARISON STUDY

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Abstract: We compared logistical issues and the catch composition, density, and size structure of nekton samples collected with a drop sampler, benthic sled, and a fine mesh cast net in shallow non-vegetated habitats of Galveston Bay, Texas. Approximately 16 cast net replicates were collected and sorted for every one drop or benthic sled sample. The drop sampler collected the greatest number of species and provided the highest density estimates for the majority of crustaceans and small demersal fishes; the sled provided comparable density estimates for penaeids and small demersal nekton, while under-representing more mobile fishes. Densities of small benthic nekton were underestimated by the cast net, but it provided the highest density estimates for larger and mobile fishes. Within the selectivity constraints of each gear, the sled and cast net provide viable alternatives to the drop sampler for sampling particular nekton from shallow open water habitats.

Key words: gear efficiency; drop sampler; benthic sled; cast net; salt marsh

Introduction

All sampling gears and techniques used to estimate population and community parameters (e.g., composition, abundance, size structure) in aquatic environments have biases or selectivities that influence their efficiency. Gear efficiency can be defined as the proportion of target organisms within a sample area that is successfully quantified, and combines the efficiency with which a gear captures or encloses the target organisms, and the recovery efficiency of those organisms from the gear (Kjelson and Colby 1977). Defined this way, gear efficiency directly relates to the accuracy of the parameters being estimated and is thus of particular interest to ecologists in designing and executing field studies (Rozas and Minello 1997). In practice, however, gear efficiency is very difficult to measure since no gears provide a complete picture of the organisms actually present in a sampling area. Accordingly, most studies testing or comparing gears present estimates of recovery efficiency and/or comparisons of population or community parameter estimates among gears or among species (e.g. Connolly 1994, Beesley and Gilmore 2008). Such studies, while rarely measuring true gear efficiency, form useful foundations for comparisons of population or community parameters among studies using different gears (Rozas and Minello 1997). They are also important for evaluating the relative efficiency of new or modified gears in reference to other widely used gears for sampling particular target nekton (Stevens 2006), or for comparing the relative efficiency of a particular gear in sampling a variety of nekton (Lyons 1986, Parsley et al. 1989).

Among the wide variety of gears used to sample nekton from shallow—water habitats, those considered to provide

more quantitative measures of density and species composition are also logistically the most difficult to operate (e.g. Kushlan 1974, Kneib 1991). Gears such as pop nets (Connolly 1994) and drop samplers (Zimmerman et al. 1984) rapidly and securely enclose a consistent area and allow for the efficient removal or recovery of trapped organisms. However, such gears typically involve expensive and complicated construction, specialized equipment and/or large numbers of personnel for deployment, and are time consuming to operate (Rozas 1992). In contrast, simple and easily deployed gears such as seine nets and trawls often significantly underestimate density or abundance for many species of nekton (Lyons 1986, Parsley et al. 1989, Allen et al. 1992). The result is that in many circumstances there is a trade—off between the gear efficiency and logistical constraints in their use for the collection of sufficient numbers of replicates. Gear selection must be based primarily on suitability for addressing the objectives of a study such that results can be reliably interpreted and that observed patterns are not simply artifacts of the sampling gear (Rozas and Minello 1997, Connolly 1999). Logistical issues are important to consider because they affect the cost of implementing a sampling program and the ability to achieve sufficient sample size and replication for valid statistical comparisons.

Estuarine systems across the northern Gulf of Mexico are usually dominated by salt marshes and shallow open water, but open water habitat generally covers more area and may contribute significantly to the support of many species (Minello et al. 2008, Fry 2008). The drop sampler was developed (Zimmerman et al. 1984) to allow comparative sampling of

Figure 1. *Simplified sketch of the design and dimensions of the benthic sled, showing the net detached. The net is fastened to the frame along the vertical and horizontal forward frame, along each skid and to the cross—bar at the rear of the two skids.*

nekton in a range of marsh habitats including shallow open water and the vegetated marsh surface. While this sampler appears to be highly efficient, and one of the few gears suitable for sampling in dense vegetation, it is time—consuming to deploy, requires specialized equipment, requires at least three personnel to operate, and it potentially collects large amounts of detritus that increases laboratory sorting time. Accordingly, we explored alternatives for sampling in shallow open water habitats where options for collecting quantitative nekton samples are more varied. In this study, we compared the usefulness of a benthic sled and a fine mesh cast net with the drop sampler.

Materials and Methods

Gear descriptions

The gears to be tested and compared include a drop sampler (Zimmerman et al. 1984, 1986), a benthic sled, and a cast net. A detailed description of the drop sampler and the technique for deploying it is provided by Zimmerman et al. (1984). The drop sampler is an open—ended fiberglass cylinder with a metal skirt around the base, is 1.82 m in diameter, 1.2 m high, and encloses an area of 2.6 m². It is suspended from a boom on the front of a shallow draft aluminum boat and moved into position quietly by personnel in the water, ensuring minimal noise and that no shadow is cast over the site to be sampled. Once in position, the drop sampler is released and falls rapidly to enclose the sample area. The sampler is pressed firmly into the mud to form a seal and all water is pumped out. Animals are collected by dip nets or by hand from within the enclosed area, or accumulated in a 1mm nitex mesh cod—end through which the water from the sampler is pumped. The sampler is then reattached to the boom and hoisted with a winch in preparation for the next sample. Occasionally, due to the nature of the substrate, it is not possible to fully drain the drop sampler

with the pump, and in such cases, the sample is abandoned as unsuccessful since all animals may not have been cleared from the enclosed area. During this study, the drop sampler was operated from a 5.5 m aluminum boat with 3 crew, the minimum number for efficient operation.

Our benthic sled was based on a design by Rooker and Holt (1997) with a 1 m wide by 0.8 m high aluminum frame on two 0.8 m long skids (Figure 1). Two tickler chains between the skids of the sled are designed to drive sedentary or buried nekton up into the mouth of the trailing net. The location of the forward tickler chain halfway along the skids ensures that nekton driven up into the water column by the chain are already enclosed by the hood of the net (Figure 1). The net is a 4 m long cone shape of 2 mm nitex mesh. Captured nekton accumulate in a 1 mm nitex mesh cod—end at the end of the net. The sled was hauled by 2 operators using 10 m long ropes attached to each skid. After positioning the sled at the beginning of a sample area, the operators moved to the endpoint of the sled haul along a semi—circular path away from the area to be sampled to minimize disturbance of the area. Each haul was terminated by lifting the sled mouth vertically clear of the water to ensure all trapped nekton were accumulated in the cod—end. Following this approach, when hauled for 10 m the sled sampled an area of 10 m², albeit with some disturbance at each end of the area sampled.

Until recently, cast nets were rarely used as sampling tools for nekton in shallow waters, apparently due to a belief that they are unreliable for providing estimates of even relative abundance of various nekton. However, several recent studies indicate that cast nets are at least as effective as other commonly used gears in providing relative density and species composition estimates (Webb and Kneib 2002, Stevens 2006, Johnston et al. 2007, Sheaves et al. 2007). The drawstring cast net used in our study was 4.88 m (16

feet) in diameter with a 4.8 mm (3/16") monofilament mesh (stretched measurement). Although theoretically the maximum area sampled by a net of this diameter would be 18.70 m², repeated tests involving casting the net on land found the functional area sampled was much smaller but consistent at 6.74 ± 0.09 m² (n = 30). In the field, only successful casts were included as replicate samples. A cast was deemed successful if it was visually estimated by the operator to have opened to ≥85% of functional sampling area, it did not snag on debris during retrieval, and no shadow was cast over the area to be sampled prior to deployment (Johnston and Sheaves 2008). The cast net was deployed by one person from the water, with an assistant to help sort the samples and record data. Both the sled and cast net teams sampled on foot and used small (1.3 x 0.6 m) buoyant plastic sleds to transport the gear and accessory equipment. The operators of each gear remained constant throughout the study, and all personnel were experienced with their respective gear types.

Study site and sampling design

We sampled shallow water habitats in the marsh complex of Gangs Bayou on the bayside of Galveston Island, Texas (Figure 2), during 2 trips, 15 October 2007 and 13 May 2008. Both trips allowed for the comparison of sample composition, species density, and nekton size structure among gears, while the design of Trip 1 also allowed a direct comparison of logistical issues in the deployment, collection, and processing of samples with each gear. Additionally, while temporal replication was not deemed necessary since we see no reason that the relative efficiency of the gears would vary through time, the two trips allowed us to sample important fishery species which do not occur year–round; namely white shrimp (*Litopenaeus setiferus*) which dominate in the fall (Trip 1), and brown shrimp (*Farfantepenaeus aztecus*) during spring (Trip 2).

On Trip 1 we designated 3 embayments in the lower part of the bayou as our sample sites (Figure 2). The 3 sites were simultaneously sampled with one gear per site during each of 3 sampling periods, such that each site was sampled with each of the 3 gears. For each sampling period the cast net and sled were operated continuously to collect as many replicates as possible during the time taken to collect 6 drop samples (about 1.5 h) before being rotated to the next site for the next sampling period. During rotation each site was left undisturbed for 20–30 min before commencement of the next sampling period. The order of gears used at a site was randomized. Replicate samples were collected 5 m into open water from the edge of the marsh vegetation; either the cast net or drop sampler centered 5 m from the marsh, or the sled towed for 10 m parallel to the vegetation 5 m into open water. Prior to sampling, we used aerial image site maps to randomly locate individual replicate sample locations with a minimum separation of 10 m, and each

replicate was allocated to a particular gear randomly. Replicates located adjacent to benthic sled tows were a minimum of 10 m from either end of the sled tow. If a cast net or drop sample was deemed a failure, the replicate location was abandoned and the operators moved on to the location of the next replicate. This design allowed for a gear to operate within a site without interference or disturbance caused by other gears, and each gear to subsequently sample undisturbed replicate locations within each site. For each replicate, the time at which the gear was deployed was recorded, along with the water depth at the sample location and at the nearest point of the adjacent marsh edge. In the laboratory, all nekton were identified and enumerated, and total length (TL), carapace length (CL), or carapace width (CW) was measured to the nearest mm. The time taken to sort each sample also was recorded.

During Trip 2 we grouped replicates within locations, with each gear collecting a single replicate at each of 15 locations throughout the broader Gangs Bayou marsh complex. This design helped to overcome potential spatial and temporal confounding associated with tide state or time of day. Replication was limited to n = 15 per gear because, with this
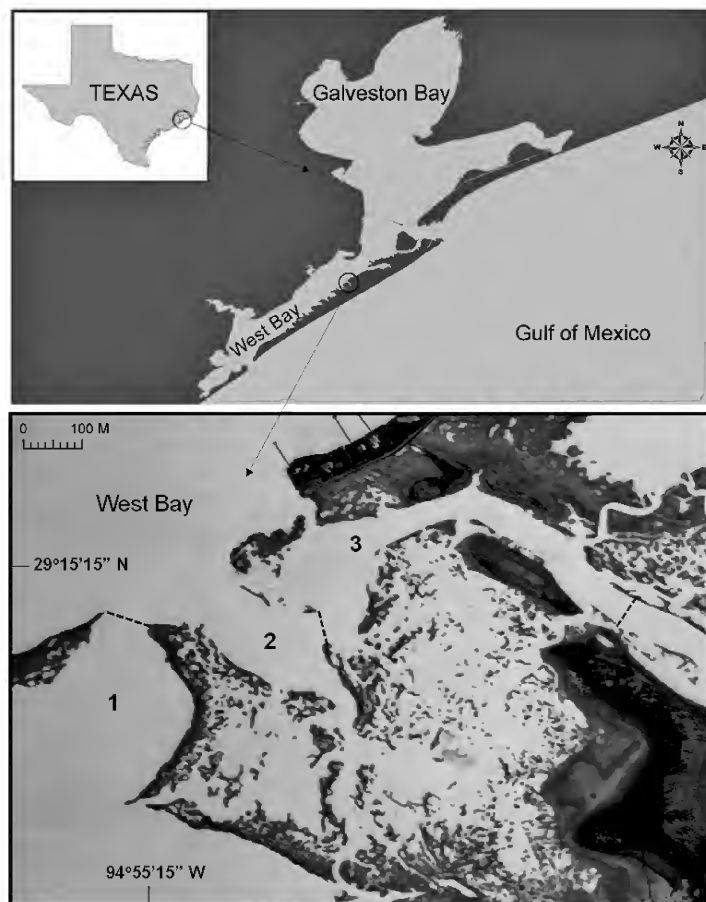
Figure 2. *Study site in Gangs Bayou, Galveston Island, Texas. Numbers and dashed lines in lower panel indicate the three embayments sampled during Trip 1. Sampling during Trip 2 was conducted throughout this and the immediately adjacent areas of Gangs Bayou.*

design, 15 samples represented a full field day with the drop sampler. A location consisted of an 85 m section of relatively uniform marsh edge. Each gear was deployed 5 m from the marsh edge as per Trip 1. To minimize and randomize any interference or disturbance between gears during positioning and deployment, gears were deployed 25 m apart in a random order in each location and the direction of the sled tow was also randomized. At each location, deployment of the cast net and drop sampler and commencement of the sled tow occurred simultaneously after operators positioned the gears while minimizing disturbance of the site. All cast net and sled samples were successfully collected, but one drop sample had to be discarded because of a failure to completely empty the cylinder with the pump. As a result, 14 samples were analyzed from each gear type during Trip 2. The time and water depth at each replicate and water depth at the edge of the adjacent marsh were recorded.

Data analysis

Univariate comparisons of the densities of abundant taxa (those contributing >2% of total catch) were conducted for each trip. For Trip 1 (n = 6 spp.), we used Latin Squares ANOVA to account for the confounded effects of site and time since each site was sampled by each gear during different sampling periods (Hicks 1973). For Trip 2 (n = 4 spp.), univariate comparisons were performed by blocked 2–way ANOVAs with gears blocked within sites. Density data for all taxa were log (x+1) transformed to improve homogeneity of variances. We used Fisher's Protected LSD post-hoc tests to compare gear density estimates when ANOVA's detected a significant effect of gear. The size structures of white shrimp and bay anchovy (*Anchoa mitchilli*; Trip 1), and brown shrimp (Trip 2), were compared among gears via paired Kolmogorov–Smirnov tests. Individuals of the other abundant taxa spanned narrow size ranges and formal comparisons of their size structures were not performed.

We also applied multivariate Classification and Regression Tree (mCART) analysis to compare species composition and densities among gears and sites for each trip (De'ath 2002). mCARTs are a powerful tool for exploring patterns in assemblage structure in data that are unbalanced, contain many zeros, and have potential for high-order interactions (De'ath 2002). Comparisons of both densities and composition were performed on log transformed data to minimize the influence of highly abundant taxa on the analyses, and the composition analysis was performed on relative density data (proportion of total sample). To avoid rare species driving the final models, only those taxa that occurred in >10% of replicates were included in the analysis (n = 12 taxa for Trip 1 and 11 for Trip 2). The trees presented were chosen based on the minimum + 1 SE rule; the smallest tree with a cross–validation error within 1 SE of the tree with the minimum cross validation error (Breiman et al. 1984).

Results

Field sampling and laboratory processing time, Trip 1

A total of 18 drop, 26 benthic sled and 40 cast net replicates were collected during Trip 1 (Table 1). The mean (± 1 SE throughout) time required to collect a sample was 14.3 (± 1.6) min for the drop sampler, 10.9 (± 0.8) min for the sled, and 7.3 (± 0.3) min for the cast net. Therefore, in the time taken to collect 6 open–water drop samples, between 8 and 10 benthic sled samples and between 11 and 16 cast net samples were collected. Samples collected by the drop sampler and benthic sled contained more animals and large quantities of debris and detritus; consequently the sorting of these samples in the laboratory was time consuming and averaged 251 ± 71 min for the drop samples and 264 ± 62 min for the sled samples. In contrast, the cast net provided

TABLE 1. *Replication, catch summary and replicate handling time for 3 gears used to sample nekton for 4.5 h from shallow open waters in Gangs Bayou, Galveston Island, 15 October 2007. ? = minimal variation, no accurate estimate.*

	Gear		
Parameter	**Drop**	**Sled**	**Cast**
Replication			
n	18	26	40
replicate area (m² ± 1SE)	2.6 ± 0	10 ± ?	6.7 ± 0.1
total area sampled (m²)	46.8	260	268
Total catch			
n	1246	3803	1511
mean density (n/m² ± 1SE)	26.6 ± 5.4	14.6 ± 3.1	5.6 ± 0.7
# of taxa	25	20	24
# exclusive taxa	5	3	10
Handling time (mean min/rep ± 1SE)			
field	14.3 ± 1.6	10.9 ± 0.8	7.3 ± 0.3
laboratory	251 ± 71	264 ± 62	9.5 ± 1.3
Total handling time/rep (hr:min)	4:25	4:35	0:17

relatively clean samples containing fewer nekton and laboratory sorting time averaged 9.5 ± 1.3 min per sample (Table 1).

Nekton composition and abundance

During Trip 1, 6,560 individuals from 38 taxa of nekton were collected in a pooled total of 84 samples. The samples were numerically dominated by white shrimp (54.8%) and bay anchovy (24.5%) (Table 2). We also collected small numbers (< 0.5% of total catch) of the portunid crab *Callinectes similis* and other fish species (*Dasyatis sabina, Synodus foetens, Mugil cephalus, M. curema, Menidia martinica, Syngnathus scovelli, Chloroscombrus chrysurus, Oligoplites saurus, Eucinostomus*

TABLE 2: *Comparison of species composition and density estimates (n/m²) for abundant species (> 0.5% from either trip) among cast net, drop sampler, and benthic sled on two field trips to Gangs Bayou, Galveston Island. Letters in parenthesis indicate homogeous subsets determined from univariate comparisons of abundance for the most abundant species sampled during Trip 1 (6 spp.) and Trip 2 (4 spp.). See Table 1 for details of replication during October 2007. For May 2008, n = 14 replicate samples for each gear.*

Group			October 2007				May 2008			
taxon	common name	cast net	drop	sled	total n	cast net	drop	sled	total n
Decapod Crustacea									
Penaeidae									
Farfantepenaues aztecus	brown shrimp	<0.1	0.1	0.1	34	2.0 (a)	3.5 (a)	2.1 (a)	614
Litopenaeus setiferus	white shrimp	1.7(a)	8.8 (b)	10.5 (b)	3595	–	–	–	0
Sergestidae									
Acetes sp.		<0.1 (b)	2.4 (a)	1.2 (a)	425	–	–	–	0
Palaemonidae									
Palaemonetes pugio	daggerblade grass shrimp	0	<0.1	<0.1	3	0.1	0	0.2	29
Palaemonetes spp.	grass shrimp	0	<0.1	0.1	29	–	–	–	0
Portunidae									
Callinectes sapidus	blue crab	<0.1 (c)	1.5 (a)	0.3 (b)	163	0	0.1	<0.1	9
Fishes									
Engraulidae									
Anchoa mitchilli	bay anchovy	3.2 (b)	8.7 (a)	1.3 (c)	1609	0.2 (a)	1.7 (a)	0.4 (a)	139
Clupeidae									
Brevoortia patronus	Gulf menhaden	<0.1	0	0	1	31.6 (a)	11.8 (b)	0.1 (b)	3334
Atherinopsidae									
Menidia beryllina	inland silverside	0.3	<0.1	0	91	0.7 (a)	1.6 (a)	<0.1 (a)	129
Sparidae									
Lagodon rhomboides	pinfish	<0.1	<0.1	0	9	0.5	0.5	<0.1	68
Sciaenidae									
Bairdiella chrysoura	silver perch	–	–	–	0	0.3	0	0.1	44
Leiostomus xanthurus	spot	<0.1	0.1	<0.1	7	0.1	0.4	<0.1	28
Sciaenops ocellatus	red drum	0.1 (b)	0.7 (a)	0.3 (b)	138	–	–	–	0
Gobiidae									
Ctenogobius boleosoma	darter goby	0 (c)	1.6 (a)	0.3 (b)	145	<0.1	0.8	0.2	59
Gobiosoma bosc	naked goby	<0.1	0.3	0.2	70	–	–	–	0
Microgobius gulosus	clown goby	0	0.7	0.1	61	–	–	–	0
M. thalassinus	green goby	<0.1	0.8	0.1	78	–	–	–	0

argenteus, Cynoscion arenarius, C. nebulosus, Micropogonias undulatus, Bollmannia communis, Gobionellus oceanicus, Citharichthys spilopterus, and *Symphurus plagiusa)* not listed in Table 2. The drop sampler sampled the smallest total area (46.8 m²) and the lowest total number of individuals (1,246) but collected the greatest number of taxa (25) and the highest total nekton densities from its 18 replicate samples (Table 1). Five of the taxa collected by the drop sampler (small crabs and benthic fishes) were not collected in either of the other gears (Table 2). The highest densities for 21 of the 38 taxa collected during Trip 1 were sampled by the drop sampler. The 26 replicate benthic sled tows sampled an area of 260 m² and collected the greatest number of individuals (3,803) and the lowest number of taxa (20). Three taxa (1 individual

each) were sampled only by the sled, and the sled provided the highest density estimates for 5 of the 38 taxa collected during Trip 1. The 40 cast net samples covered a similar area to the sled (about 270 m²), and collected 1,511 individuals from 24 taxa (Table 1). The cast net sampled 10 taxa not collected by the other gears, primarily mobile and/or larger fishes including 19 mullet (*M. cephalus* and *M. curema*) and 5 sand seatrout (*C. arenarius*) (Table 2). Twelve of the 38 taxa collected during Trip 1 were sampled in the highest density by the cast net.

mCART analysis revealed that while the cast net tended to sample lower densities of most taxa compared to the drop and sled (Figure 3b), the composition of the cast net and drop samples were quite similar, both containing a higher
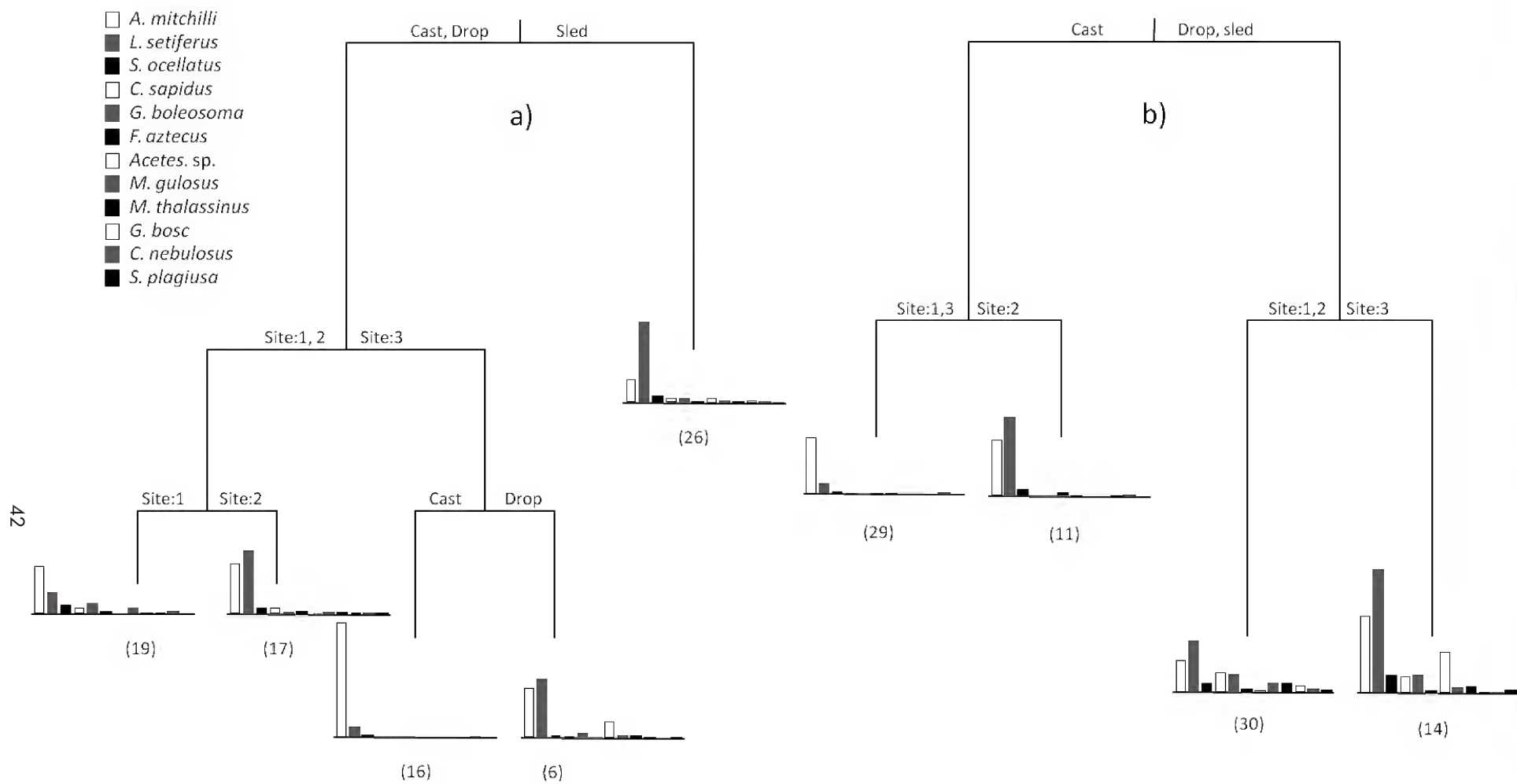
Figure 3. *Multivariate Classification and Regression Trees comparing a) the composition, and b) (log) density of nekton samples among sites and gears, for taxa appearing in >10% of replicates during Trip 1. Bars from left to right in histograms on each leaf follow species names top to bottom in legend, and indicate a) relative abundance, and b) log density. Values in parenthesis are the sample size (number of replicates) forming each leaf. See Table 2 for full species names.*
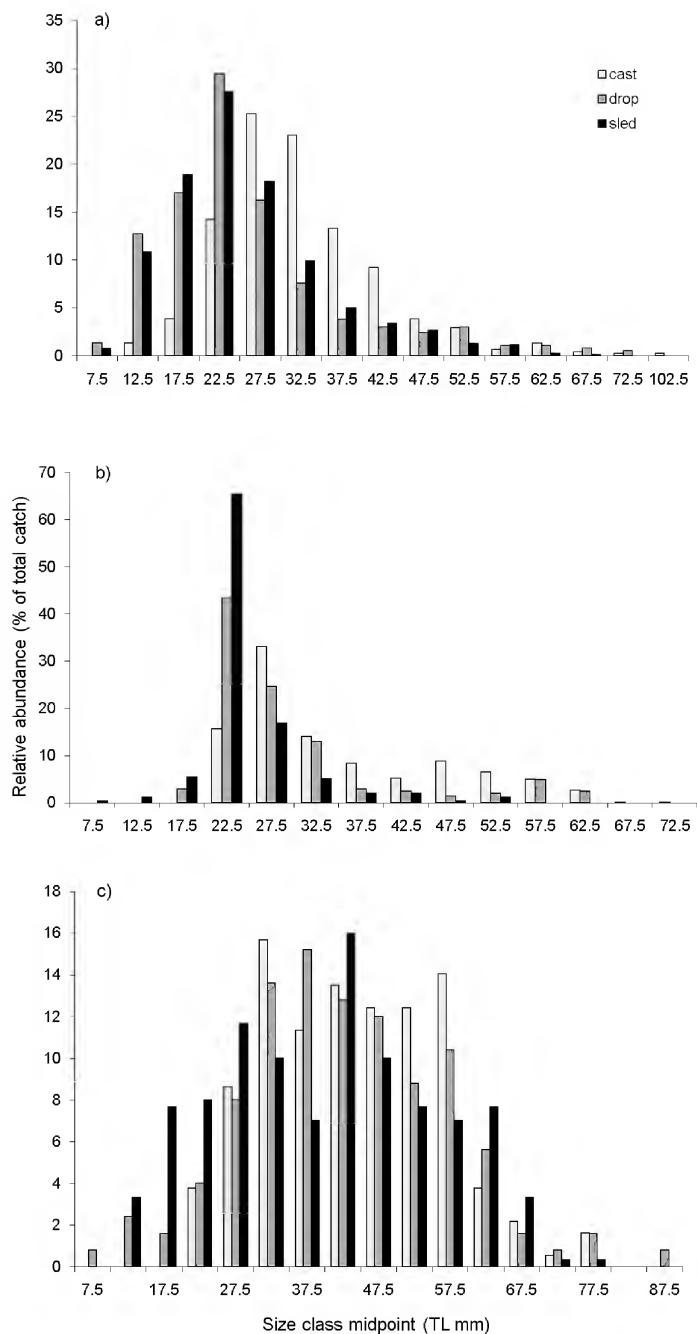
Figure 4. *Comparison of relative abundance within size classes among gears for a)* Litopenaeus setiferus, *and b)* Anchoa mitchilli *during Trip 1 (October 2007) and c)* Farfantepenaeus aztecus *on Trip 2 (May 2008). Note the discontinuous final size class in a).*

proportion of bay anchovy than the sled samples (Figure 3a). In both trees, the further splits by site indicate that nekton composition and density varied more among sites (embayments) than between gears within sites.

White shrimp were sampled in significantly higher densities (mean/m² ± 1SE) by the drop (8.8 ± 3.1) and sled (10.5 ± 2.5), than by the cast net (1.7 ± 0.4) ($F_{2,77}$ = 15.78, p = 0.0001) (Table 2). The cast net underrepresented small white shrimp (<30 mm) (Figure 4a) resulting in a size-frequency distribu-

tion significantly different from that sampled by the drop and sled (Kolmogorov–Smirnov, p < 0.01 for each comparison). When the densities of only larger (≥ 30 mm) white shrimp were compared, the cast net again sampled the lowest mean density (1.08 ± 0.31) compared to the drop (1.86 ± 0.72) and sled (2.61 ± 0.69), however only the difference between the cast net and sled was significant ($F_{2,77}$ = 5.19, p = 0.008). Among the other abundant species sampled during Trip 1, red drum (*Sciaenops ocellatus*), blue crab (*Callinectes sapidus*), darter goby (*Ctenogobius boleosoma*), and *Acetes* spp. all showed significant gear effects with the drop ≥ sled ≥ cast net (Table 2). In contrast, the bay anchovy densities were drop (8.7 ± 2.6) > cast net (3.2 ± 0.5) > sled (1.3 ± 0.3) ($F_{2,77}$ = 12.59, p = 0.0001). The cast net again under–represented small individuals (<20 mm TL) but provided the highest density estimates for larger bay anchovy (>35 mm TL) (Figure 4b). Both the drop and sled effectively sampled small individuals, while the sled under–represented larger anchovies.

During Trip 2 4,498 individuals from 24 taxa were collected from the 42 samples analyzed (Table 2). Nekton were numerically dominated by Gulf menhaden *Brevoortia patronus* (74.1%), and brown shrimp (13.7%). We also collected small numbers (< 0.5% of total catch) of cephalopods (*Loligo* sp.) and other fish species (*Elops saurus*, *S. foetens*, *M. cephalus*, *M. curema*, *Orthopristis chrysoptera*, *C. arenarius*, *C. spilopterus*, *Paralichthys dentatus*, and *Sphoeroides parvus*) not listed in Table 2. The cast net sampled 19 taxa. Of these, 4 were not sampled by either the drop or sled, and comprised two individual unidentified clupeids, two *Anchoa* sp., one white mullet *M. curema* and one summer flounder *Paralichthys dentatus*. Seven of the 24 taxa collected during Trip 2 were sampled in the highest density by the cast net, 16 had the highest density in drop samples, while one was sampled in the highest density by the sled. Seventeen taxa were collected by the drop sampler, with one individual each of the sand seatrout, and an unidentified juvenile sciaenid representing the 2 taxa not sampled by the other gears. The benthic sled collected 15 taxa, all of which were sampled in at least one of the other gears. mCART analyses revealed that during Trip 2 both nekton densities and species composition varied more between sites than among gears within sites (Figure 5). There was a weak gear effect at some sites where the composition of the cast net samples was dominated by Gulf menhaden, while the drop and sled samples were dominated by brown shrimp and bay anchovy but contained few menhaden (Figure 5a).

The cast net sampled significantly higher densities of Gulf menhaden (31.6 ± 13.4) than either the sled (0.1 ± 0.1) or drop sampler (11.8 ± 9.6) ($F_{2,26}$ = 8.82, p = <0.01), while the densities of the other two abundant taxa from Trip 2, inland silverside (*Menidia beryllina*) and bay anchovy, were not significantly different among gears (Table 2). Mean brown
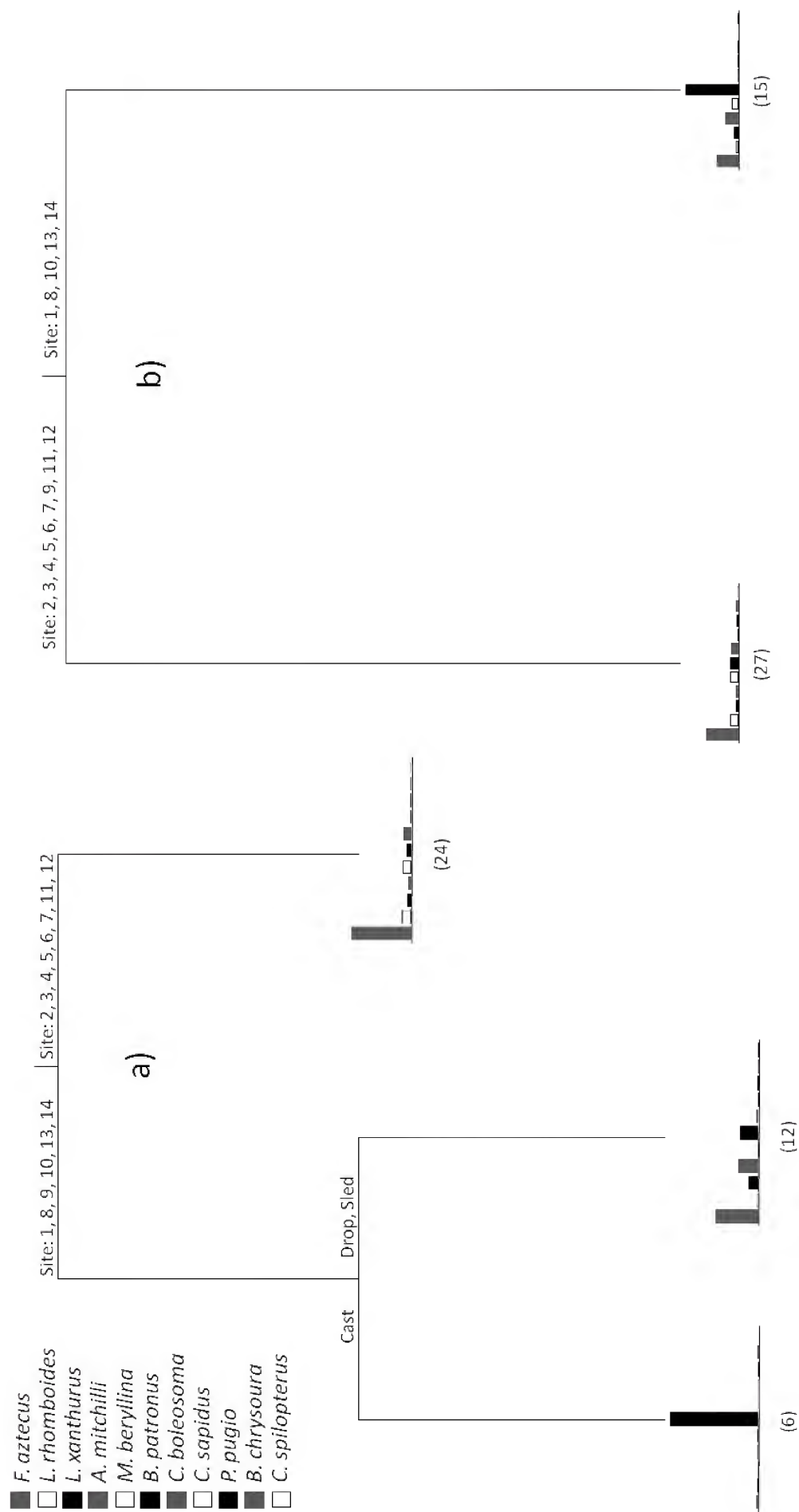
Figure 5. *Multivariate Classification and Regression Trees comparing a) the composition, and b) (log) density of nekton samples among sites and gears during Trip 2. Bars from left to right in histograms on each leaf follow species names top to bottom in legend; e.g., tall bar in histogram for the left-most leaf in 5a represents B. patronus. See figure 3 caption for full details and Table 2 for full species names.*

shrimp density estimates were 3.5 ± 1.1 from the drop sampler, 2.1 ± 0.5 from the sled, and 2.0 ± 0.4 from the cast net (Table 2), but these differences were not significant. As for white shrimp during Trip 1, the cast net underrepresented smaller brown shrimp (< 25 mm TL), and the difference in size structure between the cast net and sled was significant (Kolmogorov–Smirnov, p < 0.01) (Figure 4c).

Discussion

Sampling logistics

Drop samplers have been used to estimate nekton densities across a variety of shallow–water estuarine habitats (e.g. Howe et al. 1999, Minello and Rozas 2002, Shervette and Gelwick 2008). Testing in a cleared marsh pond stocked with a known number of shrimp indicated that the sampler provides accurate density estimates for penaeid shrimp in open waters (Zimmerman et al. 1986). Deployment of the drop sampler requires a boat that is modified with a boom and winch to hoist the sampler and a pump to drain water from the sampler (Zimmerman et al. 1984). Three experienced personnel were able to collect a drop sample in shallow open water in an average of around 15 min. There is minimal opportunity for reducing sampling time with the drop sampler because most of the factors influencing sampling time are related to gear characteristics and the environment being sampled rather than logistical issues of the sampling methodology or number of personnel. Water depth affects the time to pump water from the sampler, particularly for large–volume drop samplers. Substrate type and depth affect the ability to form a complete seal with the sampler necessary to drain water from the enclosure. For example, fine detritus present in many Louisiana marshes can make a seal difficult, particularly in deeper water where water pressure pushing up through the substrate is higher. The presence of oyster shell, gravel, or woody debris also can prevent the formation of a good seal with the substrate. If a complete seal cannot be formed and maintained for long enough to drain and clear the enclosure, the sample is abandoned as unsuccessful, using up valuable time for the collection of successful replicates. However, in the present study this occurred for only one of the 33 drop samples deployed and was thus of minor significance.

The nature of the substrate also influences the difficulty in finding and collecting trapped animals from successfully drained drops. The pump intake is usually screened to prevent damage from larger items, however thick detritus can rapidly block the screen, so regular cleaning adds to sample collection time. Finally, laboratory processing time is greatly extended for samples containing large amounts of detritus. Despite these issues limiting replication, the drop sampler is one of the few gear types generally successful across a range of substrates including heavily vegetated habitats.

The benthic sled is efficiently operated by 2 personnel,

and it took around 10 min per replicate sample. In shallow water habitats, operators can tow the sled by hand, negating the need for a boat if sites are accessible by road. Water depth and substrate type had a minimal effect on sample collection time in our study, but at sites with abundant fine detritus the sled net can become clogged rendering it ineffective. The detritus collected in the fine-meshed net also increases the sorting time needed in the laboratory.

The cast net was the most rapidly deployed gear of the 3 tested, taking on average a little over 7 min per sample in the field. It provided relatively clean samples of fewer nekton than the other gears, and thus sorting time in the laboratory was also rapid. Similar to the sled, water depth has a negligible effect on replicate time, while obstructions on the substrate such as oysters or woody debris may snag the net, rendering it ineffective. Experienced operators can collect replicate samples of relatively consistent sampling area (Johnston and Sheaves 2008, this study), however the area sampled could potentially vary among operators. Consequently, the functional area sampled should be measured for each operator/net. Sampling time per replicate can be reduced further by the use of a small boat to move more rapidly among sites and to use as a platform for more easily throwing the net. Using our sampling protocols, about 16 cast net replicates were collected and processed for each drop or sled sample.

While the logistical issues discussed above must be considered, they are ultimately of secondary importance compared to selecting a gear that will provide reliable data to address the objectives of a study. Regardless of ease of use, a gear with biases or artifacts that interact with treatments is inappropriate and should not be used (Peterson and Black 1994). While sampling gear can be used to measure relative abundance, there is always the concern that gear efficiency will vary with environmental factors or habitat characteristics of interest, and this concern is heightened when efficiency is low (Rozas and Minello 1997, Connolly 1999).

Nekton composition

The three gears provided broadly similar views of the nekton composition and relative abundance from the shallow, non-vegetated, open–water habitats sampled. During Trip 2, the catch composition and density varied more among sites than among gears within sites, with the exception of a few sites where the cast net sampled large numbers of Gulf menhaden. The distribution of maximum density estimates among gears for the more abundant taxa indicates that each gear has varying efficiency across the nekton assemblage, i.e., each gear samples certain components of the nekton assemblage better than the other gears and other components of the assemblage (Allen et al. 1992).

Despite the broad similarities, there were important differences in assemblage composition among gears. The drop

sampler provided the highest density estimates for the majority of demersal crustacea and small fishes including the gobiids and small sciaenids, and was also effective at sampling some of the pelagic fishes such as atherinids, clupeids, and engraulids. The cast net generally sampled the greatest densities of larger and or mobile/pelagic taxa such as the atherinids, carangids, clupeids, and mugilids, while under-representing small benthic nekton such as many of the crustacea and gobiids. The benthic sled, while providing the highest density estimates for few taxa, often provided similar density estimates to the drop sampler for demersal crustacea, gobiids, and sciaenids, while capturing few of the more mobile/pelagic fishes.

Higher densities in the cast net of mobile pelagic nekton such as Gulf menhaden suggest gear avoidance of the drop sampler and sled. In particular, this species appeared to simply avoid capture by the slowly-towed benthic sled. The drop sampler also estimated significantly lower densities of Gulf menhaden than the cast net. Despite efforts to minimize disturbance of the sample site, some nekton may respond to the approach of the boat and personnel by moving out of the area thus avoiding capture. In addition, the smaller sample area of the drop sampler in relation to the cast net may increase avoidance at the time of gear deployment.

The cast net data underrepresented smaller size classes of some abundant taxa, and this result was likely related to the larger mesh size of the cast net allowing smaller enclosed animals to escape. The high density estimates of large, mobile, and pelagic fishes along with the under representation of more sedentary taxa also suggests that some of the underrepresented taxa in the cast net escape from the net during recovery after casting, rather than that they avoid being enclosed. After deployment, the draw strings on the cast net gradually purse the lead line of the net to trap enclosed nekton. During this process there may be multiple opportunities for enclosed nekton staying close to, or buried in, the substrate to escape beneath the lead line, while fishes such as mullet and menhaden remain in the water column and are securely enclosed. Substrate type and topography are likely to affect the probability of escape of benthic associated taxa, and thus sampling areas with variable substrates may result in variable catch efficiency of the cast net more so than the drop or sled.

Trade-offs

The 4.8 mm (3/16") mesh cast net used was the smallest meshed commercially produced net we could find. The low SE values associated with the nekton density estimates from the cast net, particularly during Trip 1 where a higher level of replication was achieved, suggests a relatively stable efficiency of the gear, even if it consistently under samples smaller nekton which escape through the net mesh. Based on the available cast nets and the density and size structure

estimates from this study, it is clear that cast nets are not a useful sampling tool if estimates of the density of the smallest size classes of nekton are required. However, where the focus of the study is on larger nekton in shallow open water habitats with similar substrates, cast nets provide an easily deployable and inexpensive alternative that allows vastly greater replication than more complex gears.

The benthic sled and the drop sampler provided similar density estimates for white shrimp, brown shrimp, and a range of small and sedentary nekton. When total replication time (field, lab, and personnel) is considered, the sled requires marginally less effort. Given the requirement of a specially modified vessel and trained personnel to deploy the drop sampler, the benthic sled described here may be a useful alternative for researchers sampling small nekton from open water habitats where abundant detritus does not render it ineffective. The sled seems particularly effective at sampling penaeid shrimp across the size range found in estuarine habitats, and Stunz et al. (2002) reported density estimates of red drum collected with a benthic sled that were similar to those from a drop sampler. Use of the sled is partially limited due to its inability to provide the discrete samples from specific microhabitats which can be collected with the drop or cast net. Decreasing the sled tow length to much less than 10m would likely result in significant site disturbance during gear positioning and deployment.

Despite sampling the smallest area, the drop sampler collected the highest number of taxa and provided the highest density estimates for the greatest number of taxa over the two trips, highlighting its high efficiency relative to other gears (Rozas and Minello 1997). It also has the distinct advantage over many other gears of being able to sample in a variety of habitats including heavily vegetated habitats such as dense sea grass beds and the vegetated marsh surface (Zimmerman et al. 1984, Howe et al. 1999, Shervette and Gelwick 2008). Given the significance of such habitats to a variety of nekton of ecological and economic importance, it is clearly advantageous to have a sampling gear such as the drop sampler that provides high (and therefore the most accurate) density estimates across a number of habitats.

Shallow water nekton assemblages typically show very high spatio–temporal variability. Many studies examining this fauna require comparisons among a range of locations and times. In such cases, the slight loss of accuracy in density estimates for some species obtained with the cast net relative to the more time consuming gears may be outweighed by the ability to collect a vastly greater number of replicates. For example, the differences among gears in density estimates of bay anchovy were proportionally similar for Trip 1 and Trip 2, yet these were only significant during Trip 1 when a much greater level of replication was achieved. In many cases the limits on replication with the more complex gears, and subsequent limits on statistical power to detect important differ-

ences among treatments, may render these gears unsuitable despite higher efficiency in sampling some components of the nekton assemblage. Conversely, the differing efficiency of each of the gears tested, and indeed of all sampling gears, suggests that despite the obvious logistical constraints, the best representation of the shallow water nekton assemblage as a whole may be obtained by combining data across multiple gears.

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Odd Association and Range Extension of *Caligus rufimaculatus* Wilson, 1905; Caligidae, Siphonostomatoida, Copepoda

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ODD ASSOCIATION AND RANGE EXTENSION OF *CALIGUS RUFIMACULATUS* WILSON, 1905; CALIGIDAE, SIPHONOSTOMATOIDA, COPEPODA

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Introduction

The Caligidae (Siphonostomatoida, Copepoda) comprises more than 465 parasitic species, over 250 of which belong to *Caligus* Müller, 1785 (Boxshall and Halsey 2004). *Caligus* spp. are primarily marine; but some representatives routinely inhabit brackish or fresh water (Margolis et al. 1975). Some *Caligus* spp. have been widely reported from several oceans, others have been documented from a single location, and a few have only been collected as free-swimming individuals not associated with a host (Margolis et al. 1975). *Caligus* spp. range from being stenoxenous to euryxenous, with most species infecting actinopterygians (Actinopterygii), a much smaller group exclusively or non–exclusively infecting chondrichthyans (primarly elasmobranchs; Elasmobranchii, Chondrichthyes) (Margolis et al. 1975, Tang and Newbound 2004), and one species non–exclusively infecting an invertebrate (Ruangpan and Kabata 1984). Herein, we report a modest range extension for *Caligus rufimaculatus* Wilson, 1905 based on specimens collected in an odd association with a dead dolphin in the northern Gulf of Mexico (GOM) and we contribute new details regarding the morphology of the parasite.

Materials and Methods

Copepods were collected from a bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821) (Delphinidae, Odontoceti). The dolphin (juvenile male, 199.5 cm total length) was discovered dead on 26 December 2005, partially submerged under a dock in shallow water at the southern edge of Choctawhatchee Bay in Miramar Beach, Florida. Responders from the Southeast Fisheries Center (Panama City Beach, FL) collected the carcass on 30 December 2005 (the only dead animal noted in the area at that time) and moved it to a refrigerator. Copepods were collected during necropsy on 31 December 2005 from the skin of the ventral caudal region of the body and fixed in 10% formalin. It is not known if the copepods were alive at the time the dolphin was removed from the water and no lesion was grossly apparent where the copepods were attached. This dolphin stranded during a brevetoxin–associated unusual mortality event in which 93 dolphin strandings were documented from 19 September 2005 to 30 April 2006 (Gaydos et al.[1]). For taxonomic study, copepods were cleared in lactic acid into which a small amount of lignin pink had been dissolved. Fine pins mounted in the tips of thin wooden dowels were used to dissect copepods, and the wooden slide technique of Humes and Gooding (1964) facilitated the study of intact specimens and dissected appendages. Copepods were examined using bright-field microscopy. Measurements were made using a stage micrometer and illustrations were made using a camera lucida. Three specimens (2 females, 1 male) were studied using a scanning electron microscope (SEM) after routine preparation (CO_2 critical point drying, gold-palladium sputter coating, mounting on metal stubs with 2-sided sticky tape). Copepod terminology used herein conforms mostly to that of Boxshall and Halsey (2004) and host nomenclature and systematics follows Compagno (2005) for members of Chondrichthyes, FishBase (Froese and Pauly 2008) for other fishes, Reynolds III and Powell (2002) for manatees, and Jefferson et al. (1993) for other marine mammals. Copepod vouchers remain in the personal collection of the senior author.

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Results and Discussion

About 30 copepods were collected from the dead dolphin and 24 individuals (6 ovigerous females, 11 non—ovigerous adult females, and 7 adult males) were each identified as *C. rufimaculatus* Wilson, 1905 (Figure 1A) based on information in Cressey (1991) and Suárez—Morales et al. (2003). In their remarks regarding *Caligus amblygenitalis* Pillai, 1961, Ho and Lin (2004) noted that few *Caligus* spp. possess an accessory process on all three outer elements of the second exopodal segment of leg 1. They included *C. rufimaculatus* as one of said species based on the illustration of leg 1 provided by Cressey (1991). However, in his text description of *C. rufimaculatus*, Cressey (1991) stated that the outermost element did not exhibit an accessory process. In his original description of *C. rufimaculatus*, Wilson (1905) did not report any of the three outermost elements (referred to by Wilson as claws) as possessing an accessory process and most recently, Suárez—Morales et al. (2003) reported that their non-type exemplars exhibited an accessory process on elements 2 and 3 (referred to by those authors as spines) among the three outer elements. Our observations corroborate the illustration of leg 1 (but not the text description) of Cressey (1991) in that we observed adult females and adult males to possess three outer elements each with an accessory process (Figure 1B). Ho and Lin (2004) also remarked that *C. amblygenitalis* can be distinguished from *C. rufimaculatus* in that the former species possesses a large patch of spinules ventrally on the basis of leg 2. Here it is noted that there seems little doubt, based on their detailed description of *C. amblygenitalis*, that Ho and Lin (2004) mistakenly remarked that the aforementioned patch of spinules is found on leg 2, as clearly their text description and illustrations establish the patch as residing on the basis of leg 1. Our observations of the adult female and male of *C. rufimaculatus* revealed tiny cuticular bumps on the ventral surface of the basis of leg 1 (Figure 1C) and no cuticular projections on the ventral surface of the basis of leg 2. These bumps (not reported by others) seem smaller than the homologous spinules illustrated by Ho and Lin (2004). Lastly, Ho and Lin (2004) remarked that another feature distinguishing *C. amblygenitalis* from *C. rufimaculatus* is an "unipectinate outer spine with strong teeth" on the second segment of leg 2. Our observations of the homologous feature of *C. rufimaculatus* revealed it to be a spine with a marginal membrane on each side, described as a "fringes" by Cressey (1991).

Few copepod species infect or otherwise associate with mammals (Boxshall and Halsey 2004) and we believe the following to be a complete accounting of said species: *Pennella balaenopterae* Korea and Danielson, 1877, (Siphonostomatoida) is a mesoparasite that infects mysticets (Mysticeti) and odontocets (Odontoceti) (Hogans 1987) and the northern elephant seal, *Mirounga angustirostris*, (see Dailey et al. 2002); *Balaenophilus unisetus* Aurivillius, 1897
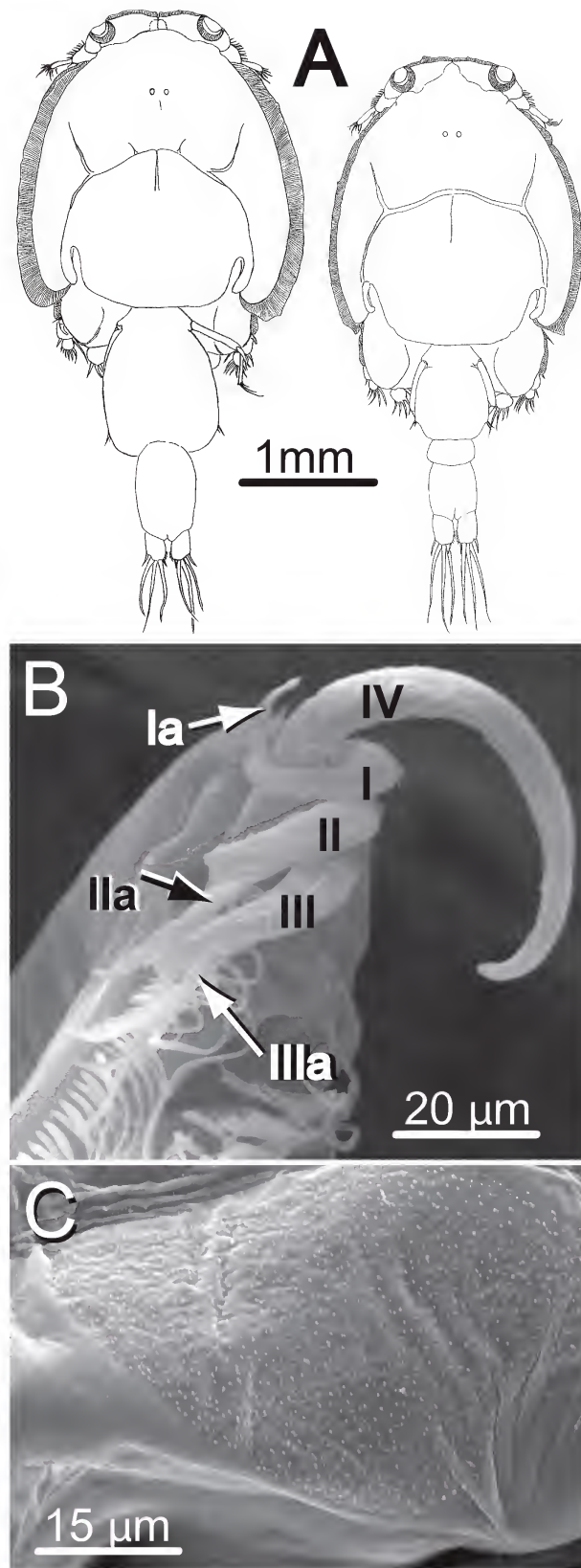
Figure 1. Caligus rufimaculatus *collected from a dead bottlenose dolphin,* Tursiops truncatus, *in Choctawhatchee Bay, Florida. A. Adult female (left) and adult male (right). B. Tip of leg 1 exopod (adult female) showing three outermost elements (I, II, III) and their accessory processes (one per element; Ia, IIa, IIIa). Note: the base of seta IV (not visible in image) lies just medial to the base of element III. C. Ventral view of the basipod of leg 1 showing a patch of tiny cuticular bumps.*

TABLE 1. Published host fish records for Caligus rufimaculatus Wilson, 1905.

Class
  Order
    Family
      Species
	Location	Attachment site on host	Reference

Chondrichthyes			
Rajiformes			
Rhinobatidae			
*Rhinobatos lentiginosus**	in or about Lemon Bay, FL	body surface	Bere 1936
Myliobatidae			
*Aetobatus narinari**	in or about Lemon Bay, FL	body surface	Bere 1936
Mobulidae			
"devilfish"[1]	in or about Lemon Bay, FL	about mouth	Bere 1936
Actinopterygii			
Mugiliformes			
Mugilidae			
Mugil cephalus	not reported	not reported	Wilson 1905, 1932
	in or about Lemon Bay, FL	mouth, body surface	Bere, 1936
	Biscayne Bay, FL	skin	Skinner 1975
	Sapelo Island, GA	gills, body surface	Rawson 1977[2]
Beloniformes			
Belonidae			
Strongylura timucu	in or about Lemon Bay, FL	body surface	Bere 1936
Cyprinodontiformes			
Fundulidae			
Fundulus heteroclitus	Woods Hole , MA	body surface	Wilson 1905, 1932
	about Beaufort, NC	body surface	Wilson 1908
F. majalis	Woods Hole, MA	body surface	Wilson 1905, 1932
Perciformes			
Serranidae			
*Centropristis striata**	about Placida, FL	not reported	Cressey 1991
Pomatomidae			
Pomatomus saltatrix	in or about Lemon Bay, FL	mouth	Bere 1936
	Maricá, Rio de Janeiro, Brazil	body surface	Luque et al. 1998
Carangidae			
Oligoplites palometa	Sepetiba Bay, Brazil	gills	Takemoto & Luque 2002
O. saliens	Sepetiba Bay, Brazil	gills	Takemoto & Luque 2002
O. saurus	in or about Lemon Bay, FL	mouth, body surface	Bere 1936
Lutjanidae			
Lutjanus synagris	about Placida, FL	not reported	Cressey 1991
Gerreidae			
Eucinostomus gula	about Placida, FL	not reported	Cressey 1991
E. pseudogula[3]	in or about Lemon Bay, FL	body surface	Bere 1936
Haemulidae			
*Haemulon plumierii**	about Placida, FL	not reported	Cressey 1991
Orthopristis chrysoptera	about Placida, FL	not reported	Cressey 1991
Sparidae			
*Diplodus holbrookii**,[4]	about Placida, FL	not reported	Cressey 1991
Lagodon rhomboides	about Placida, FL	not reported	Cressey 1991
Scaridae			
Nicholsina usta	about Placida, FL	not reported	Cressey 1991
Ephippidae			
Chaetodipterus faber	in or about Lemon Bay, FL	body surface	Bere 1936
Trichiuridae			
Trichiurus lepturus	on North American coast	not reported	Wilson 1905[5]
Tetraodontiformes			
Monacanthidae			
*Stephanolepis hispidus**	about Placida, FL	not reported	Cressey 1991
Ostraciidae			
*Acanthostracion quadricornis**	about Placida, FL	not reported	Cressey 1991

* indicates that the host name used in that record was herein changed to conform to nomenclature in FishBase (Froese and Pauly 2008).

[1] *Mobula hypostoma* noted by author as the most probable host species.

[2] Results published in Rawson (1977) represent a portion of the dissertation results presented in Rawson 1973.

[3] Host binomen not listed in FishBase (Froese and Pauly 2008); also referred to as "the mojarra" by author (Bere, 1936; p. 582-583).

[4] Family entry of host in appendix of Cressey (1991; p. 18) signals an error regarding host name in text (p. 14).

[5] Wilson's (1905; p. 573) identification reassigned as *C. rufimaculatus* by Parker (1969).

(Harpacticoida) inhabits the baleen of several rorqual species (*Balaenoptera*, Balaenopteridae) (see Bannister and Grindley 1966); *B. manatorum* (Ortíz, Lalana, and Torres—Fundora, 1992) inhabits the skin of the Antillean manatee, *Trichechus manatus manatus*, (see Suárez—Morales 2007); *Harpacticus pulex* Humes, 1964 (Harpacticoida) was discovered on sloughed skin of a captive—held bottlenose dolphin and captive—held Florida manatee, *T. m. latirostris*, (see Humes 1964); and *Caligus elongatus* Nordmann, 1832 (Siphonostomatoida) was reported attached to a dead bottlenose whale, *Hyperoodon ampullatus*, (see O'Reilly 1998). This report adds another *Caligus* sp. to the list of copepods associated with mammals; and for completeness we add that occurrences of caligids temporarily attaching to humans have been reported (Kurochkin and Kazachenko 1975, as reported by Ruangpan and Kabata 1984, O'Reilly 1998). Cases of copepods attaching to humans aside, it is notable that amongst the aforementioned copepods, only *C. elongatus* and *C. rufimaculatus* have been reported from mammals as well as representatives of other classes. Considering numbers of species and phylogenetic scope, *C. elongatus* and *C. rufimaculatus* have each been reported from a numerous and diverse variety of hosts (Margolis et al. 1975; Table 1). However, whether being euryxenous regarding fish hosts is a prerequisite for their ability to associate with marine mammals is unknown and certainly there are other euryxenous *Caligus* spp. that are not known to associate with mammals (Margolis et al. 1975). In the present case, no data support or refute the notion that the specimens of *C. rufimaculatus* were actually feeding on the bottlenose dolphin, and whether or not the copepods had attached to the dolphin prior to its death likewise remains unknown. A lack of dead fish in the immediate vicinity of the dead dolphin did not support a notion that the copepods had abandoned moribund fish hosts and settled on the dolphin; however, red tide related fish kills had occurred in Choctawhatchee Bay for months before and during the time of the dolphin stranding. This case is more curious because it involved about 30 copepods, unlike the case reported by O'Reilly (1998) of two *C. elongatus* attached to a dead whale.

The known geographic distribution of *C. rufimaculatus* has expanded significantly since the species was first discovered (Table 1). Prior to this report the species was considered to patchily inhabit western North Atlantic coastal waters from Woods Hole, Massachusetts to Biscayne Bay in southern Florida (Wilson 1905, 1908; Rawson 1973, 1977; Skinner 1975), GOM coastal waters off southern Florida and the Yucatán Peninsula, Mexico (Bere 1936, Cressey 1991, Suárez—Morales et al. 2003), and western South Atlantic waters off Maricá and in Sepetiba Bay, Rio de Janeiro, Brazil (Luque et al. 1998, Takemoto and Luque 2002). This report extends the species range to include the northern GOM and in doing so it negates the comment of Cressey (1991) that *C. rufimaculatus* does not occur in said region. *Caligus rufimaculatus* has been collected from at least 22 species of fishes, together representing 18 families and 6 orders (Table 1). The phylogenetic scope of these hosts (elasmobranchs to members of the Tetraodontiformes) is remarkable, as is their ecological scope, ranging from small, shallow—water, and euryhaline species (e.g., *Fundulus heteroclitus*) to larger constantly swimming and wide—ranging nearshore species (e.g., *Pomatomus saltatrix*), as well as a species known to be capable of inhabiting relatively deep water (*Trichiurus lepturus*) (Froese and Pauly 2008). In addition, *C. rufimaculatus* is capable of attaching to a wide array of host surfaces, from smooth and scaleless skin (e.g., *Rhinobatos lentiginosus*, *Trichiurus lepturus*, *Tursiops truncatus*) to heavily scaled skin (*Mugil cephalus*) to hard plated skin (*Acanthostracion quadricornis*) to gills (*M. cephalus*, *Oligoplites palometa*) (Table 1). Its ability to move about freely away from a host and associate with many species would seem to predispose *C. rufimaculatus* to be a sea louse capable of negatively impacting a wide variety of aquaculture operations. Yet we are unaware of any such reports. Based on its aforementioned abilities, its known distribution within the GOM, and the general pattern of water flow within the GOM, we expect that future records of *C. rufimaculatus* will document much more of the GOM as part of its range.

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Observations at a Multispecies Parrotfish (Scaridae) Spawning Aggregation Site at Bermuda with Notes on the Predation Behavior of Black Grouper (*Mycteroperca bonaci*)

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OBSERVATIONS AT A MULTISPECIES PARROTFISH (SCARIDAE) SPAWNING AGGREGATION SITE AT BERMUDA WITH NOTES ON THE PREDATION BEHAVIOR OF BLACK GROUPER (*MYCTEROPERCA BONACI*)

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Introduction

Domeier and Colin (1997) defined a reef fish spawning aggregation as "a group of conspecific fish gathered for the purposes of spawning, with fish densities or numbers significantly higher than those found in the area of aggregation during the non–reproductive periods." They also distinguished between resident and transient spawning aggregations. The principal characteristics of resident aggregations are: 1) fish are drawn from a relatively small, local area and the spawning site can be reached through a short migration. The site often lies within the home range of the participating individuals; 2) they occur at a specific time of day over numerous days and usually last only a few hours; and 3) they take place daily during an often lengthy reproductive period of the year. Parrotfishes (Scaridae), surgeonfishes (Acanthuridae) and wrasses (Labridae) form resident spawning aggregations (Domeier and Colin 1997). In comparison, transient spawning aggregations have the following characteristics: 1) fish are typically drawn from a relatively large area and must often travel days or weeks to reach the aggregation site; 2) they occur during a very specific portion of the year, usually 2–3 months and are entrained to the lunar cycle; 3) they persist for a period of days or at most a few weeks (Domeier and Colin 1997). Groupers (Serranidae), snappers (Lutjanidae) and rabbitfishes (Siganidae) are classified as forming transient spawning aggregations. As these families include many of the most important commercial species in tropical fisheries, the majority of research on spawning aggregations has been conducted on transient aggregation spawners (Whaylen et al. 2004, Matos–Caraballo et al. 2006, Heyman and Kjerve 2008)**.** Sadovy and Domeier (2005) discuss some of the challenges of evaluating and managing reef fish spawning aggregations and associated fisheries. In contrast to transient spawning aggregations, relatively little research has been conducted on resident spawning aggregations as these species are not generally harvested in commercial fisheries, an exception being the landings of scarids and acanthurids in the trap fisheries of the wider Caribbean (Munro 1983). Scarids play an important role as grazers in the economy of coral reefs and thus understanding the spawning aggregations of these species is important for resource management (Hawkins and Roberts 2003). In the tropical western Atlantic, there are only two species of parrotfish (*Sparisoma rubripinne*, *Scarus iserti*) and two species of surgeonfish (*Acanthurus coeruleus*, *A. bahianus*) which have been adequately documented to form resident spawning aggregations (Sadovy et al. 2008).

However, the first study of any reef fish spawning aggregation was conducted on a resident aggregation of red-fin parrotfish (*S. rubripinne*) on a fringing reef in St. John, U.S. Virgin Islands (Randall and Randall 1963). Other studies on resident spawning aggregations of scarids in the Caribbean include those of Colin (1978) in Jamaica and Colin and Clavijo (1988) in Puerto Rico. Scarids have complex socio–sexual systems and exhibit both group and pair spawning (Thresher 1984). The most common relationship between sex and color pattern in scarids is exhibited by the presence of two distinctive color patterns; terminal–phase (TP) males and initial–phase (IP) males and females (Thresher 1984). TP males usually have brightly–colored patterns while IP fish are generally drab in appearance (Bohlke and Chaplin 1968). Robertson and Warner (1978) describe sex change, coloration, and mating behavior of 10 species of Caribbean parrotfishes from the San Blas islands of Panama, including all of the species discussed in this study.

The objective of the present study was to describe the spawning behavior of three different species of parrotfishes at the same spawning aggregation site with detailed timing sequences. In addition, observations of other species known to form resident spawning aggregations (i.e., surgeonfishes) and the predatory behavior of black grouper
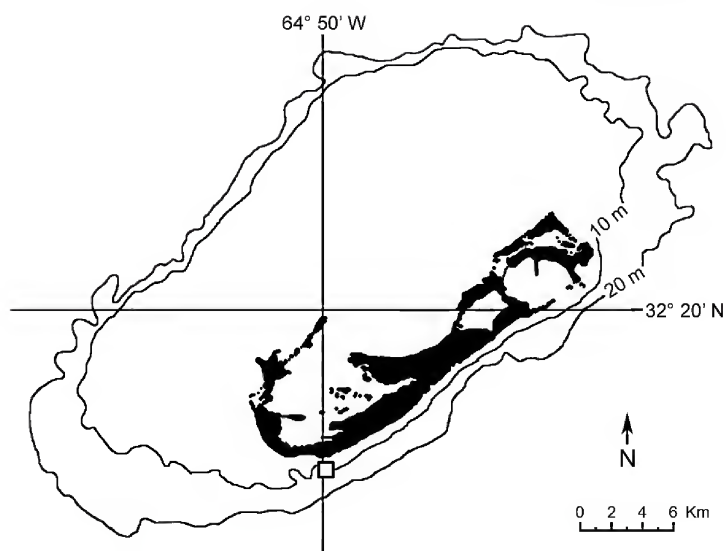
Figure 1. *Map showing location of multispecies scarid spawning aggregation site (northeastern quadrant of square) off the southwest coast of Bermuda just outside the 10 m bathymetric curve. The 20 m bathymetric curve is also indicated.*

(*Mycteroperca bonaci*) at this aggregation site are included.

Site Description

The spawning aggregation site was located just outside the breaking reef line along the southwest coast of Bermuda about 500 m from the shoreline (Figure 1). The site was a patch reef surrounded by sand in 10–12 m water depth. The top of the reef was relatively flat with low cover (< 20%) of live coral. Another larger reef 5–6 m to seaward had greater vertical relief and more crevices than the spawning site reef. The aggregation site was within the protected area (300 m radius) of the Marie Celeste dive site (J. Pitt, pers. comm., Marine Resources Division, Bermuda) which is a permanent no–take MPA (Marine Protected Area). Water temperature at 10 m depth was 24°C on both 9 June and 27 June 2003; it was 25°C on 7 July 2003.

Materials and Methods

Observations (see below) were made in the afternoon on 9 June and in the morning on 27 June and 7 July 2003 (Table 1). Two divers using SCUBA made stationary point counts while suspended in the water column, estimating the number of each scarid and acanthurid species present at the site. Counts and notes were recorded on waterproof paper on slates. Observations concentrated on those species believed to form resident spawning aggregations. Divers also noted behaviors of spawning fishes, color changes and times of occurrence of spawning events. The number and sizes of black grouper at the site were estimated and predation behavior was noted. At the end of each observation period, divers compared notes to arrive at a consensus about counts and observations.

Two types of spawning behavior were observed: group–spawning and pair–spawning. Definitions of the terms used in this paper follow Domeier and Colin (1997): **Spawning Rush** – a rapid burst of swimming, usually vertical or steeply inclined, that culminates in the release of gametes at its apex and the rapid return of the fish to the substrate or aggregation; **Group–Spawning** – spawning rush consisting of more than two fish, often many individuals. The group usually consists of a single female and multiple males; spawning may occur in the absence of elaborate courtship; **Pair–Spawning** – courtship and spawning by a single male and single female. Pair–spawning may occur within, or in the absence of a spawning aggregation; **Subgroup** – a portion of a larger spawning aggregation that interacts as a unit, often leading to spawning by the subgroup; and **Gamete Cloud** – gamete concentration left suspended in the water column by spawning fishes. Since eggs are nearly transparent, the visible cloud is primarily the result of sperm; may remain visible from a few seconds to a few minutes depending upon the currents and the amount of sperm.

Results

The location where spawning was actually observed was confined to an area of 30–40 m² on the eastern side of the patch reef. However, the larger reef to seaward of the spawning site appeared to be used by some scarids as a shelter area and some fish were observed to swim across the sand channel to the spawning site to join conspecifics already on the site. Scarids appeared to arrive at the site from different directions, usually in small groups.

Scarid spawning behavior

Summaries of the observations of spawning behavior of three different species of scarids, principally *S. rubripinne* and the queen parrotfish, *Scarus vetula*, are found in Table 1. Both of these species were observed spawning on 27 June and 7 July. The third species observed in spawning mode was the stoplight parrotfish, *Sparisoma viride*, but those observations were made on 9 June and were limited to 3 spawning events (Table 1). When divers arrived at 0955 h on 7 July, spawning was already in progress with both *S. rubripinne* and *S. vetula* spawning at the same time (Table 1). Sunrise on 7 July was at 0617 h Atlantic Daylight Time and it is not known when spawning commenced or for how long it continued after observations ceased. The total number of spawning events documented over the 3 days of observations were: *S. rubripinne* – 46, *S. vetula* – 11 and *S. viride* – 3 (Table 1). Two other species of scarids, the redband parrotfish, *Sparisoma aurofrenatum* and the princess parrotfish, *Scarus taeniopterus*, were recorded at the site but neither was observed to spawn (Table 1). Two species of acanthurids, the blue tang, *Acanthurus coeruleus*, and the ocean surgeon, *A. bahianus*, were also observed and were seen moving across the spawning site in groups (Table 1) but they did not re-

TABLE 1. *Summary of diving observations at a multispecies spawning aggregation site in 2003 off the southwest coast of Bermuda. Observations on species in 2 families are presented, parrotfishes (Scaridae) and surgeonfishes (Acanthuridae). Species are listed alphabetically within family commencing with Scaridae. IP = initial phase and TP = terminal phase fishes. Lunar phase — dbfm: days before full moon, dafm: days after full moon. See text and Figure 2 for behavioral details.*
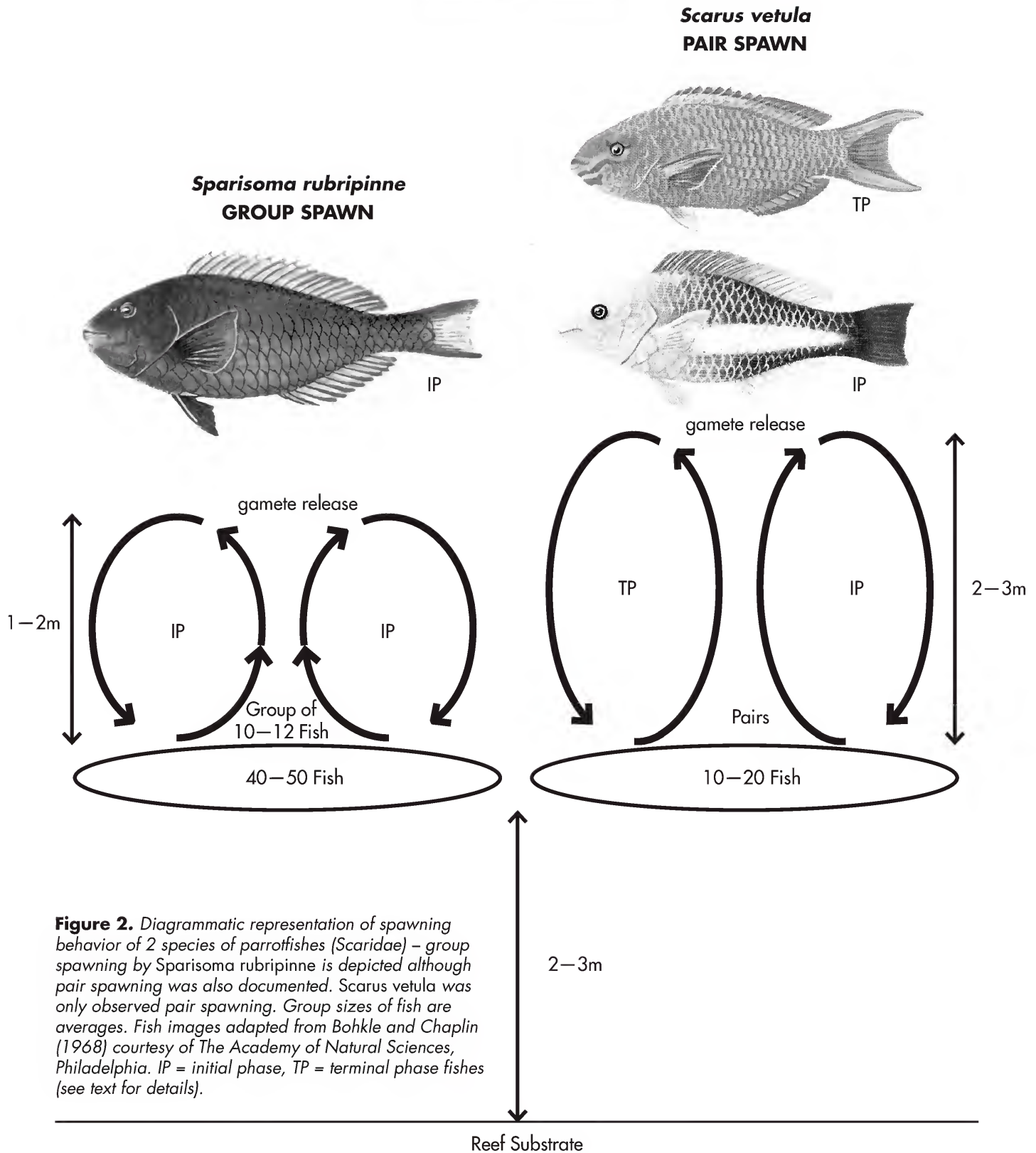
Date and observation period (h)	Lunar phase	*Mycteroperca bonaci* present (predation attempts)	Observed species	Estimated abundance	Observations
June 9 (1300 — 1355 h)	5 dbfm	3 (0)	*Sparisoma aurofrenatum*	15	Milling and TP chasing IP fish, no spawning
			Sparisoma rubripinne	15	Milling but no chasing or spawning
			Sparisoma viride	60	Milling, TP chasing IP fish, 3 pair spawns
			Acanthurus coeruleus	40	Group streaming across spawning site, moving offshore
June 27 (1045 – 1140 h)	13 dafm	8 (3)	*Scarus taenopterus*	10	Mixed with group of *Scarus vetula* streaming, no spawning behavior
			Scarus vetula	55	Groups of TP (25) and IP (30) fish streaming separately, mixed at site followed by 3 pair spawns
			S. rubripinne	25	From 1055 –1102 h, 6 group spawns (10—12 fish/group), all IP, gamete clouds, TP males not active during spawning
			Acanthurus bahianus	50	Milling seaward of spawning site
			A. coeruleus	55	Streaming across site moving offshore
July 7 (0950 – 1100 h)	7 dbfm	9 (6)	*S. vetula*	20	From 0955—1045 h, 8 pair spawns (1TP+1IP), TP color changes, gamete clouds
			S. rubripinne	100	Milling at site, from 0955—1024 h, 26 group spawns (10—12 fish /group), all IP, gamete clouds. From 1035—1045 h, 14 pair spawns (1TP+1IP), gamete clouds
			A. bahianus	25	Streaming across site moving offshore
	Total predation attempts = 9				**Total spawning events:** *Scarus vetula* = 11 *Sparisoma rubripinne* = 46 *Sparisoma viride* = 3

main during observations. These species did not exhibit any courtship or spawning behavior.

The spawning behavior of the two principal scarid species, S. *rubripinne* and S. *vetula* is illustrated in Figure 2. In S. *rubripinne*, subgroups of 10–12 IP fish moved together upward (1–2 m) from the main group in a 'rapid spawning rush' (Domeier and Colin 1997) with the release of gametes at the apex of the rush, which was clearly visible. These fish then immediately descended back to the main group. The entire spawning sequence occurred in 2–3 sec. Several S. *rubripinne* TP fish were present but did not appear to participate in the spawning sequence. During a period of intense spawning activity, group–spawns were occurring every 20–30 sec (Table 1). On 7 July, S. *rubripinne* switched from

group–spawning to pair–spawning (1 TP + 1 IP) after a brief interval when no spawning activity was recorded. A total of 14 pair–spawns were recorded in a 10 min period (Table 1). In one instance, 3 separate pair–spawns occurred in a period of only 10 sec.

Scarus vetula was only observed to pair–spawn (Figure 2) but the spawning sequence was similar to that described for S. *rubripinne*. Pairs (1 TP + 1 IP) were observed to rise upward (2–3 m) from the main group in a spawning rush with gamete release at the apex of the rush (Figure 2). The spawning sequence lasted only a few seconds and, on 7 July, a total of 8 pair–spawns occurred at the site over a period of 50 min (Table 1). One TP male was observed to pair spawn twice in 30 sec and on descending after the second spawning rush,

Scarus vetula
PAIR SPAWN

Sparisoma rubripinne
GROUP SPAWN

TP

IP

IP

gamete release

gamete release

TP

IP

1—2m

IP

IP

2—3m

Group of
10—12 Fish

Pairs

40—50 Fish

10—20 Fish

2—3m

Figure 2. *Diagrammatic representation of spawning behavior of 2 species of parrotfishes (Scaridae) – group spawning by* Sparisoma rubripinne *is depicted although pair spawning was also documented.* Scarus vetula *was only observed pair spawning. Group sizes of fish are averages. Fish images adapted from Bohkle and Chaplin (1968) courtesy of The Academy of Natural Sciences, Philadelphia. IP = initial phase, TP = terminal phase fishes (see text for details).*

Reef Substrate

a black grouper lunged at this TP male and then chased it for about 5 m (see section below). Pair–spawning of S. *viride* was observed only 3 times but appeared to be similar to that described above for S. *vetula.*

Predation behavior of black grouper

During observation periods, the number of black grouper in close proximity (about 10 m) to the spawning aggre-

gation site ranged from 3–9 (Table 1). The majority of fish were estimated to be >120 cm fork length, a size considered to be male in this sex–changing species (Luckhurst 2010). These fish generally hovered above the substrate in a loose group, were quiescent, and were mostly observed at the seaward end of the sand channel leading to the spawning aggregation site. As scarid spawning activity intensified (Table 1),

several black grouper slowly moved up the channel and positioned themselves near the perimeter of the site. The scarids formed what is termed here a "prey envelope" around the black grouper as it approached, as if the grouper were "in a bubble." However, the scarids always maintained a minimum distance between themselves and the black grouper as it moved.

A total of 9 predation attempts on scarids were observed during which lunges were followed by brief chases. These predation attempts almost all occurred when the fish were descending towards the substrate following a spawning rush (Figure 2). Predation behavior was observed toward both S. rubripinne and S. vetula (total of 57 spawning events) but no attempts were successful.

Discussion

Scarid spawning behavior

Given the limited observations at this multispecies spawning aggregation site, generalizations about the overall spawning behavior of the three scarid species described are not warranted. However, this is the first documentation of a resident spawning aggregation site in Bermuda used by more than one species of scarid. In addition, the presence of other known species of resident spawners (i.e., acanthurids) suggests that this spawning site may be used by other species as well. Although no acanthurid spawning was observed, it is possible that spawning did occur outside of the observation periods. For example, Colin and Clavijo (1988) reported that both A. coeruleus and A. bahianus formed resident spawning aggregations in the late afternoon near the shelf break in Puerto Rico, a time period outside of the observation periods in this study.

Sparisoma rubripinne was observed at the site on the 3 days of observation but spawning was only observed in the morning. In contrast, Randall and Randall (1963) never saw this species at their spawning site until 1100 h and the majority of spawns occurred in the afternoon in their study. Furthermore, they only observed group–spawning whereas I report both group spawns and pair spawns sequentially during the same observation period in the morning. Consistent with the observations by Randall and Randall (1963) and Robertson and Warner (1978) in the San Bias islands of Panama, I did not observe S. rubripinne TP males participating in group spawning but only in pair–spawning. Robertson and Warner (1978) did not observe any group–spawning and only observed pair–spawning in the late afternoon. It appears from these limited observations that there is considerable variability in the spawning modes and times of this species.

Scarus vetula was only observed during morning observations but spawning occurred on 27 June and 7 July with only pair–spawning (1 TP + 1 IP) being recorded when there were up to 55 fish at the site. Colin and Clavijo (1988) reported only pair–spawning of S. vetula TP males and IP fe-

males only during mid to late morning and at no other time. Their description of TP males swimming in the water column a few meters above the bottom and then being joined by a female S. vetula in a spawning rush is broadly consistent with the behavior outlined here. Colin and Clavijo (1988) also report that gametes in this species are often released (at the apex of the spawning rush) 6 m or more above the substrate which is consistent with my estimate. Robertson and Warner (1978) never witnessed spawning in this species, although Randall and Randall (1963) report seeing a S. vetula TP male pair–spawn with an IP fish in St. John, U.S. Virgin Islands.

The third parrotfish, S. viride, observed spawning at the site did so in the afternoon (9 June) and was not present during morning observations. Only three pair–spawns (1 TP + 1 IP) were observed. Robertson and Warner (1978) and Colin and Clavijo (1988) reported that this species pair–spawned throughout the day over a broad range of times.

Predation by black grouper

None of the 9 observed predation attempts by black grouper on spawning scarids was successful, however, the total number of spawning events (57) for the 2 principal species observed represent a small sample size. As a result, these data should not be used as an estimate of predation success. Colin and Clavijo (1988) witnessed thousands of spawning events and they reported that attempts by piscivores to prey on spawning fishes were rare. They were unable to confirm a single successful predation event. Sancho et al. (2000) determined that piscivores differentially selected group–spawning species during spawning rushes over pair–spawning and non–spawning fishes. Predation attempts by piscivores on a group spawning scarid, Chlorurus sordidus, were observed in only 3.6% of the total number of spawns (3,749) witnessed in this species. Of these attacks, only 5.2% were successful (Sancho et al. 2000). Overall, attack rates by piscivores on adult spawning fishes were higher than by planktivores feeding on recently released eggs. No feeding on gamete clouds by planktivores was observed in this study.

In Bermuda, black grouper are known to feed on scarids as identifiable scarid remains were found in the stomach contents of several black grouper examined while conducting a fishery biology study on this species (Luckhurst, pers. obs.). There may be an increased frequency of predation attempts by black grouper while scarids are spawning as they may be less wary but this would require further study to evaluate. Sancho et al. (2000) found that almost 85% of all recorded predation attempts took place on fishes involved in spawning rushes. My limited observations suggest similar behavioral selection by this large benthic predator on spawning fishes rather than on groups of fishes milling over the substrate.

Acknowledgements

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