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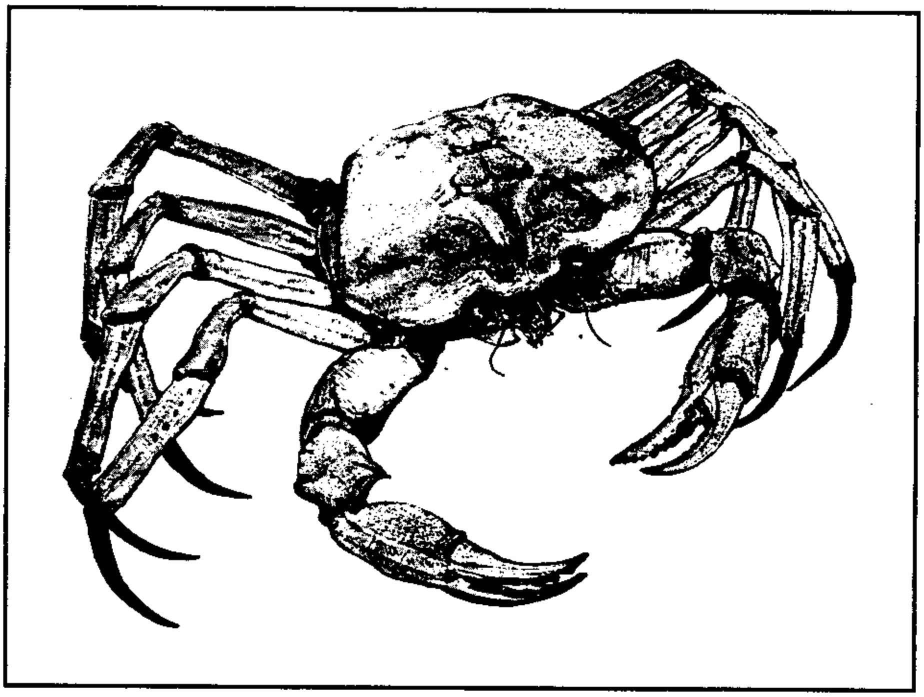
Geryonid Crabs and Associated Continental Slope Fauna:

A Research Workshop Report

William J. Lindberg and Elizabeth L. Wenner
Editors



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GERYONID CRABS AND ASSOCIATED CONTINENTAL SLOPE FAUNA:

A RESEARCH WORKSHOP REPORT

edited by

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PREFACE

Considerable research in recent years has been invested in the basic biology, ecology, and fisheries of deep-water crabs, Family Geryonidae. These efforts have been concentrated off the southeastern United States and southwest Africa, following earlier work from the Mid-Atlantic states of the U.S. to the Canadian Maritime Provinces. Species of primary interest have been the golden crab, _Chaceon fenneri_, and the red crabs _C. maritae_ and _C. quinquedens_. Only a fraction of recent data has been published. Yet, the many investigators and sponsoring agencies sought to foster regional comparisons, to inform the commercial fishing industry and resource agencies, and to provide guidance for future research investments.

On January 19 and 20, 1989, an invited panel of scientists, fishermen, and Sea Grant Extension faculty met in Tampa, Florida to share their results, conclusions, and latest hypotheses. This report, as a summary of workshop presentations and discussions, is simply a vehicle by which that expertise can be delivered to a broader audience. In due time, the data summarized here should appear in the primary literature. Meanwhile, persons needing greater detail are encouraged to communicate directly with individual investigators.

This international workshop was possible only through the generous sponsorship of several agencies and institutions acknowledged on page iii. We are particularly grateful for the administrative leadership and financial support provided by Alan Hulbert and the National Undersea Research Center, James Cato and the Florida Sea Grant College Program, Margaret Davidson and the South Carolina Sea Grant College Program, and Hugh Popenoe and the International Program of the Institute of Food and Agricultural Sciences, University of Florida. Workshop arrangements were made by Twila Stivender and Monica Lindberg, much to the relief of the workshop co-chairmen, and the report was prepared for publication by Margaret Lentz and Karen Swanson of the South Carolina Wildlife and Marine Resources Department.

Ultimately, credit for this workshop's success belongs to the attendees for their enthusiastic participation. We very much appreciated the collegial exchanges, critical comments, and good

humor. Much remains to be learned about these crabs, and about the ecology of the upper continental slope in general. It is our hope that continued research will give cause for a similar gathering in the not too distant future.

W.J. Lindberg and E.L. Wenner
Workshop Co-Chairmen
April 1989

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STUDIES ON SYSTEMATICS OF GERYONID CRABS

Raymond B. Manning[1]

Geryonid crabs are true deep-water crabs that are found in all oceans except in the eastern Pacific above Chile. They occur in depths from about 100 to more than 2800 meters.

Studies on the geryonids have revealed that the family comprises three genera: Geryon proper, with three anterolateral teeth on the carapace, containing two species restricted to the northeastern Atlantic and Mediterranean: G. trispinosus (Herbst) (= G. tridens (Kroyer)) and G. longipes (A. Milne Edwards). Although these are relatively small geryonids, with maximum carapace widths of about 10 cm, they are fished commercially.

Two new genera, Chaceon and Zariquieyon, both with five anterolateral teeth on the carapace, have been recognized in the family. Zariquieyon containing one small species from ca. 2800 meters in the western Mediterranean, was named for R. Zariquey Alvarez. Its size, width about 2 cm, shape, and inflation of the carapace distinguish it from the other geryonid genera. The second new genus, Chaceon, was named for Fenner A. Chace, Jr., and contains all of the species now placed in Geryon that have five anterolateral teeth on the carapace. It includes 11 named species previously placed in Geryon, G. affinis (A. Milne Edwards & Bouvier), northeast Atlantic; G. chuni (Macpherson), Namibia and South Africa; G. erytheiae (Macpherson), Valdivia Bank; G. fenneri (Manning & Holthuis), west Atlantic; G. granulatus (Ingle), west Africa; G. granulatus (Sakai), Japan; G. inghami (Manning & Holthuis), Bermuda; G. macphersoni (Manning & Holthuis), southwest Indian Ocean and South Africa; G. maritae (Manning & Holthuis), west Africa; G. paulensis (Chun), south Indian Ocean; and G. quinquedens (Smith), northeast Atlantic. Ten new species have been described from this genus: 4 South American, 2 from St. Helena, 1 northeast Atlantic, 1 Mediterranean, 1 from Madagascar, 1 from the central Pacific. Members of this genus are large crabs, with carapace widths ranging from about 7.5 to more than 20 cm.

Characters that are important in the group include: color in life (red, tan, purple/brown, or white; most species are red or tan), size of carapace spines in adults, presence of an outer carpal spine on the cheliped, presence of a distal dorsal spine on

[1]National Museum of Natural History, Crustacean Division, Smithsonian Institution

the walking legs, relative length of the walking legs, and structure of the dactylus of the walking legs, whether laterally compressed or dorsoventrally depressed. Depth range of adults may also be important.

Some generalizations about geryonid crabs are:

Red species often live in deeper waters than tan ones.

Young crabs of some species may live in considerably deeper water than adults. The young of _G_. _trispinosus_ settle up to 1000 meters below the adults and migrate upwards as they mature.

In some species young crabs resemble adults, whereas in others they may be very different.

Often two or more species occupy the same general geographic range. When this happens they may be separated by depth range of the adults.

Geographic ranges of species tend to be limited. Species do not occur beyond one part of one ocean, and may even be restricted to limited areas, such as undersea banks.

ANIMAL-SEDIMENT RELATIONSHIPS INVOLVING RED CRABS (CHACEON QUINQUEDENS) ON THE SOUTHERN NEW ENGLAND UPPER CONTINENTAL SLOPE

R.B. Whitlatch[2]
J.F. Grassle[3]
L.F. Boyer[4]
R.N. Zajac[5]

In August 1987, we began a multi-year research program on the southern New England upper continental slope (depth: 750 m) using the submersible DSR/V Johnson-Sea-Link. Our focus was on the role that large, mobile epifaunal organisms have on the biological and physical structure of the seafloor. Specifically, we were interested in examining the red crab (Chaceon quinquedens), one of the most abundant epifaunal species at the study site. We postulate the effects of Chaceon on the seafloor are manifold. For example, redcrab excavation activities are likely to greatly effect the type and abundance of infaunal species and potentially interfere with the natural near-seabed hydrodynamic regime. Alterations in near-bottom velocity profiles can greatly enhance or reduce larval settlement and subsequent recruitment in soft-bottom areas, as well as alter the accumulation and/or removal of organic materials settling on the seafloor. In addition, the activities of these organisms can greatly alter the physical structure of the seafloor by destroying or altering sedimentary texture and fabric, in addition to accelerating rates of sediment mixing (relative to the surrounding seafloor). Such activities can greatly alter the movement of particulate and dissolved materials into and out of the seafloor.

Results of our six-day cruise indicated the study site was extensively bioturbated by the activities of epifaunal organisms. Analysis of videotape transects showed that roughly one-half of the seafloor was covered by a variety of biogenic structures.

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[5]Environmental Sciences Program, University of New Haven

Small depressions and pits (less than 20 cm in diameter) were the most abundant structures, while mounds, caves, tunnels, and troughs were less abundant. Although it appeared that red crabs were the principal biotic modifiers of the seafloor, other species (e.g., galatheid crabs, white hake and flounder) were also acting as primary sediment excavators or modifiers of the red crab-produced biogenic structures. Sediment samples collected from several types of structures indicated significant differences in pore water content and bulk grain-size analysis; particularly in the upper 2-4 cm of the sediment. X-radiographs of the sediment indicated biogenic mixing depths to 20-30 cm, as well as extensive heterogeneity in micro-topographic relief and sediment textural fabric.

Patchiness of biogenic features was quantified over a range of spatial scales. Three of the eight biogenic structures (small pits, large depressions and caves) were aggregated at the scale of a single photograph (3.9 m^2). Measures of patchiness as a function of length scale indicated structure-specific patterns of patchiness on scales of tens to hundreds of meters.

The most abundant epifaunal organisms at the study site were red crabs (8.9 organisms/100 m^2), followed by eelfish (Aldrovandia affinis, 6.7/100 m^2), galatheid crabs (Munida sp., 2.7/100 m^2), Gulf Stream flounder (Citharichthys arctifrons, 1.2/100 m^2), rat-tail fishes (Coryphaenoides carapinus, 1.1/100 m^2) and white hake (Urophycis tenuis, 0.7/100 m^2). Many of these organisms were found in association with various biogenic structures and their individual dispersion patterns were, in part, auto-correlated with patterns of micro-topographic relief.

Samples of infauna revealed the study site was dominated by polychaetes (65.8% of the total fauna), bivalves (9.8%), aplacophorans (4.7%), and amphipod crustaceans (3.6%). Infaunal densities averaged 198.6 per 225 cm^2, with a relatively high degree of between-sample variation. The fauna was dominated by members of the polychaete families Opheliidae, Paraonidae, Capitellidae and Acrocirridae.

Infaunal samples collected from various biogenic features (burrows, tunnels, mounds and pits) were compared to samples collected from "flat areas" (no structures present). While we are still processing samples, preliminary results indicated no discernible relationship between polychaete, molluscan and crustacean abundance and biogenic features. In addition, no apparent patterns existed between relative abundance of infaunal organisms associated with biogenic structures when compared to flat areas. Infaunal species composition, however, was highly variable between biogenic structures and areas without structures; indicating a high degree of spatial heterogeneity in species' distributions associated with epifaunal-generated disturbance of the seafloor.

Support for shipboard and submersible operations were provided by NOAA's National Underwater Research Center at The University of Connecticut (Avery Point). We thank A. Desbonnet, S. Legler-Brown and R. Petrecca for laboratory assistance.

DISTRIBUTION AND ABUNDANCE OF GOLDEN CRAB, CHACEON FENNERI, IN THE SOUTH ATLANTIC BIGHT

Elizabeth W. Wenner[6]

Exploratory trapping for golden crab, Chaceon fenneri was conducted in 1985 and 1986 off South Carolina and Georgia. Objectives were to determine depth-related changes in abundance, size, and sex composition of golden crab in the South Atlantic Bight; evaluate traps, soak time and gear performance in an effort to optimize fishing technique; and describe adult life history in terms of habitat and reproductive biology. A buoyed system with strings of six traps (three side-entry Fathoms Plus and three top-entry Florida traps) was fished in seven depth strata: 274-366 m (150-200 fm), 367-457 m (210-250 fm), 458-549 m (251-300 fm), 550-640 m (301-350 fm), 641-732 m (351-400 fm), 733-823 m (401-450 fm), and >823 m (>450 fm). A total of 770 traps collected 4387 golden crab that weighed 3936 kg.

Catches of golden crab were related to depth. Catch per trap increased from 2.3 crabs/trap (2 kg/trap) in the shallowest stratum sampled to a maximum of 12 crabs/trap (10 kg/trap) in the 458-549 m depth zone. Catches then declined to <1 individual/trap in deeper strata. Catch per trap of golden crab from this study compares favorably with catch rates reported in the Gulf of Mexico. Distribution within strata was apparently related to bottom type since catches were highest on sediments of silt-clay and globigerina ooze, while few crabs were collected from coral rubble bottom.

Sex composition changed with depth with male crabs significantly outnumbering females in depths from 274-549 m. In the 733-823 m stratum, female golden crab were significantly more numerous than males. Over all strata, male golden crab outnumbered females by 15:1. Although the data suggest segregation of the sexes by depth, it is not known whether seasonal migrations related to mating or spawning occur among golden crab.

The small number of females collected precluded any definitive statements regarding ovarian cycles or spawning patterns. Based on ovarian development, vulval condition, and presence of seminal

[6]S.C. Wildlife and Marine Resources Department, Marine Resources Research Institute

products, it appears that female golden crab reach sexual maturity at sizes between 90-110 mm carapace width. Ovigerous female C. fenneri were collected only from May-August; however, these data do not substantiate a spawning season in the South Atlantic Bight because we were unable to obtain seasonal coverage of all depth strata.

Submersible dives were made in the vicinity of trap sets to provide information on habitat types and densities of golden crab. Observations were made along 85 transects in depths of 389-567 m approximately 122 km southeast of Charleston, SC. Seven habitat types were identified during dives: soft-dimpled ooze (293-475 m); a flat foraminiferan ooze (405-567 m); rippled bottom (419-539 m); dunes (389-411 m); black pebbles (481-564 m); low rock outcrops (503-512 m); and coral mounds (503-555 m). A total of 109 golden crab were sighted within the 583,480 m^2 of bottom surveyed. Twenty-seven percent of the golden crab occurred in the flat ooze which comprised 31% of the total area surveyed. Density (mean no./1000 m^2) was significantly different among habitats, with highest values (0.7/1000 m^2) noted among low rock outcrops. Lowest densities were observed in the dune habitat (<0.1/1000 m^2), while densities for other habitats were similar (0.15-0.22/1000 m^2). The low density (1.9 individuals/ha) of golden crab in our study area and the comparatively high catch per trap suggest that golden crab are drawn to traps from a wide area.

PATTERNS OF POPULATION STRUCTURE AND ABUNDANCE FOR GOLDEN AND RED CRABS IN THE EASTERN GULF OF MEXICO

W.J. Lindberg and F.D. Lockhart[7]
N.J. Blake and R.B. Erdman[8]
H.M. Perry and R.S. Waller[9]

A Chaceon-typical bathymetric pattern of partial sex segregation (females above males) and crab size inversely related to depth was corroborated in the eastern Gulf of Mexico for golden crab, C. fenneri, and seems to hold there for red crab, C. quinquedens. Variations in that pattern, however, contradicted a simple up-slope migration with age to fully explain the distribution. Instead, sampling at medium-to-fine scales and broad scales helped refine a working model in which females distribute themselves to accommodate successful reproduction, while males distribute themselves to compete effectively for mates. Bottom type, and probably temperature, appear to set limits on distributions.

At a medium-to-fine scale, the bathymetric distribution and abundance of Chaceon spp., between 348 m and 787 m, were sampled via submersible transects and longline trapping. In addition to the Chaceon-typical depth pattern, golden crabs were most numerous at depths where most hard bottom was found (i.e., 550 m in Year 1 and 437 m in Year 2), and were seen disproportionately more often on hard bottom regardless of depth. Red crabs were found only on bioturbated West Florida Lime Mud at the deepest contours sampled, 677 m and 787 m. Large C. fenneri males and females were most numerous at shallowest depths, but large males were also in low numbers at the deepest contour. Greater proportions of crabs were mated at the two deepest contours, suggesting that large males, once paired, carry females down-slope.

Effects of season, geographic area, and depth on broad-scale patterns of catch per trap and crab size were examined with replicate trap sampling in the northeastern Gulf of Mexico. Golden

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and red crabs differed in geographic as well as bathymetric distributions. Within limits of our sampling, the geographic distribution of C. fenneri was restricted to the upper continental slope off peninsular Florida, while that of C. quinquedens was adjacent to the northern Gulf coast. Neither species was common adjacent to DeSoto Canyon. Regardless of sex, overall average catch per trap was greatest for golden crabs at the southeastern station, while that of red crabs was greatest at the northwestern station. For both golden and red crabs, the proportion of females increased counterclockwise around the northeastern Gulf, within their respective ranges. Male and female red crabs were largest at northwestern stations. Golden crabs exhibited the Chaceon-typical bathymetric pattern, but seasonal shifts occurred in population structure across depths, with some lags between geographic areas. From these patterns and other data, we suggest the Loop Current-Florida Current system has a causal relationship with behaviors affecting distributions of these species.

For golden crabs, in situ density estimates and defined ranges in the eastern Gulf combine to yield a crude estimate of adult standing stock at 7.8 million crabs, with biomass estimated at 6.16 million kg (13.6 million lbs). Alone, a sustained major golden crab fishery in the region does not seem likely. Comparable red crab estimates are not yet possible.

CHACEON MARITAE STUDIES OFF SOUTH WEST AFRICA

Roy Melville-Smith[10]

A number of papers dealing with the biology of Chaceon maritae have been published in recent years, and many of the facts that have come to light in these papers are relevant to the understanding of population trends in the fishery. Some of this information has been combined with new ideas, to explain observed changes in the annual catch rates and size frequency distributions of commercial red crab catches off South West Africa/Namibia since the early 1980's.

Chaceon maritae are slow growing, reaching both maturity and age at first capture by the commercial fishery at 7-9 years (75-90 mm carapace width (CW)). Ovigerous animals are scarce (comprising only 0, 1-0, 2% of all females sampled).

Mature C. maritae females move considerably greater distances than the rest of the population, generally in a northward direction. It is hypothesized that these animals are migrating into central or northern Angolan waters prior to becoming ovigerous. It is further hypothesized that larvae produced may migrate into surface waters and be transported southwards by the Anolan Current, to settle in their highest concentrations between the summer (22 S) and winter (15 S) frontal areas formed by the confluence of the South Angolan and Benguela currents. Catch rates have decreased on the Namibian commercial crab grounds since 1980, but not in a uniform fashion. The northern and central areas of the grounds are highly dependent on new recruits to the fishery (i.e. crabs of 75-90 mm CW). Catch rates in these two areas were reasonably constant up until 1984, but have subsequently eased, whilst oscillating markedly.

By comparison, the catch on the southern Namibian crab grounds (south of 20 S) is less dependent on new recruits to the fishery. Catch rates in this area have fallen drastically since 1980, but do not show the same fluctuations described for the northern areas.

The oscillations observed in the northern and central areas are thought to be due to the delayed effects of depletion of the brood stock by fishing pressure. It is suggested that this

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situation has led to recruitment now being more dependent on environmental conditions (e.g. favorable ocean currents for larval transport) than in the past and that the recent catch rate oscillations reflect year-classes of variable strengths entering the fishery.

The decline in catch rates in the southern area is attributed mainly to the effects of fishing mortality. It is argued that larval recruitment to this area is minimal because it falls outside of the area influenced by the Angolan Current.

FECUNDITY AND REPRODUCTIVE OUTPUT IN <u>CHACEON FENNERI</u> AND <u>C</u>. <u>QUINQUEDENS</u>

Anson H. Hines[11]

I recently compared the covariation of reproductive traits in two species of large deep-sea crabs in the family Geryonidae (Hines, 1988): Chaceon fenneri and C. quinquedens. As in other crab species (Hines, 1982, in press), body size was the primary determinant of reproductive output in the two species. However, their brood masses at 16% and 22% of body weight are considerably larger than the 10% average in most other species and are near the upper extreme of apparently typical interspecific variation (Hines, 1982, 1986, in press), but much less than certain commensal species (Pinnotheridae, Hines, in review; Haplocarcinidae, R.K. Kropp, personal communication). Egg size in the two species is also relatively large, and C. quinquedens has one of the largest reported eggs of brachyurans with marine planktonic larvae. As a result of partitioning the brood into large eggs, fecundity per brood is low compared to many species of comparable size. Comparison of covariation in reproductive traits using ANCOVA to adjust for differences in body weight showed that C. quinquedens had approximately 50% larger volume of the body cavity for accumulation of yolk, resulting in about 50% larger brood mass than C. fenneri. Despite its larger brood mass, egg size in C. quinquedens was about twice as large as in C. fenneri, resulting in about equal size-specific fecundity per brood in the two species. The published literature indicates that both species produce about one brood per year which is incubated over the winter in the northern hemisphere, although C. quinquedens exhibits low levels of brooding year-round. Large yolky eggs in C. quinquedens are likely to contribute to the nutritional flexibility of its larvae (Sulkin and Van Heukelem, 1980), but apparently have coevolved with significant changes in female morphology and reproductive output.

The following table summarized relevant parameters for size and size-dependent variables of reproductive output and fecundity in the two species. Note that both arithmetic means and least squares means are given after adjusting with ANCOVA for differences in body size.

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[11]Smithsonian Environment Research Center

	C. quinquedens	*C. fenneri*
Body Size		
Carapace Width (mm)		
Arith. Mean	107	124
(range)	(98-118)	(110-143)
Dry Body Weight (g)		
Arith. Mean	68	93
(range)	(48-90)	(74-117)
Volume of Body Cavity (cm^3)		
Arith.Mean	73	62
(range)	(47-91)	(48-73)
LSMean	83	55
Brood Size		
Dry Weight (g)		
Arith.Mean	15	15
(range)	(10-22)	(12-21)
LSMean	17	12
Egg Size		
Diameter (g)		
Arith.Mean	731	568
(range)	(648-760)	(538-588)
Volume (mm^3)		
Arith.Mean	1.636	0.767
(range)	(1.140-1.838)	(0.652-0.851)
Fecundity		
No. Eggs per Brood		
Arith.Mean	162,000	283,000
(range)	(132,000-226,000)	(188,000-371,000)
LSMean	175,000	225,000
No. Brood per Year		
Arith.Mean	1	1
(range)	(0-2?)	(0-1?)

ANNUAL REPRODUCTION IN DEEP-SEA BRACHYURAN CRABS (CHACEON spp.) FROM THE SOUTHEASTERN UNITED STATES

R.B. Erdman and N.J. Blake[12]
H.M. Perry and R.S. Waller[13]
W.J. Lindberg and F.D. Lockhart[14]

Previous studies of deep-sea reproduction patterns indicate that in the absence of changing environmental conditions, continuous cycles are to be expected. Patterns of this type have been reported for deep-sea Chaceon crabs including C. maritae and C. quinquedens. However, studies of C. fenneri from southeastern Florida and the eastern Gulf of Mexico indicate that this species exhibits a pronounced annual reproduction pattern. Additionally, C. quinquedens from the Gulf of Mexico also shows an annual pattern, although more protracted than that of C. fenneri.

Initial studies of C. fenneri were conducted on monthly samples obtained from the commercial fishery centered off Ft. Lauderdale, Florida. Oviposition begins in mid-August and continues through early October with eggs carried for six months until hatching during February and March. A single batch of eggs is produced annually, with brood size highly correlated to carapace width. Samples from this study were limited to depths between 210 and 230 m, thus data on bathymetric distributions were not obtained.

Additional research conducted in the eastern Gulf of Mexico involved seasonal sampling at five areas over depths of 311, 494 and 677 m, and permitted a comparative study of reproduction of C. fenneri and C. quinquedens. Chaceon fenneri was present only in the southern portion of the study area, while C. quinquedens was collected at all areas sampled. Each species was bathymetrically segregated with C. quinquedens found only at 677 m where temperatures were less than 8.0 C. Female C. fenneri were present at all depths sampled but were most abundant at 311 and 494 m. Temperatures at these depths averaged 12.0 and 8.0 C, respectively. Largest females were found at shallowest depths suggesting a reproduction related up-slope migration.

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Both species exhibit an annual reproduction cycle, but differences in the timing of oviposition were noted. *Chaceon quinquedens* carried eggs for nine months following oviposition during early summer, while eggs of *C. fenneri* were carried for six months subsequent to oviposition during late summer. Larvae of both species hatched during early spring.

The annual reproduction pattern shown by *C. fenneri* and *C. quinquedens* infers the presence of subtle "zeitgebers" which serve to synchronize oogenesis, vitellogenesis, oviposition and larval hatching. Variations in reproductive cycles noted may relate to environmental differences that each species experiences over its depth range on the continental slope. The upslope movement by *C. fenneri* suggests reproductive accommodation to environmental conditions that may enhance egg development time and reduce vertical distances for larvae migrating into surface waters. The molting and reproductive cycle of at least *C. fenneri* suggests that although the population as a whole undergoes annual reproduction, individuals within the population may be reproducing biannually.

REPRODUCTION IN MALE AND FEMALE CHACEON

Gertrude W. Hinsch[15]

Specimens from the deep waters of the eastern Gulf of Mexico were collected by commercial fishermen from May 1984 to May 1985 and prepared for study. The carapace width of each specimen received was measured. The reproductive tracts of the 37 males and of the 50 females were dissected out and placed in Karnovsky's glutaraldehyde-paraformaldehye fixative 91965). Tissues were post-fixed in 1% OsO_4, dehydrated in a graded acetone series and embedded in Spurr's low viscosity media (1969). Tissues for light microscopy were fixed as above and embedded in Polyscience JB-4 embedding media, sectioned on a JB-4 microtome, mounted on glass slides and stained with toluidine blue. Tissues fixed as above were critical-point dried, dehydrated, coated with gold-palladium and viewed with a Zeiss Novascan scanning microscope.

Mature male Chaceon fenneri are larger than mature females (9.5-14.5 cm vs 13.5 - 18 cm). The reproductive tracts are typical of brachyuran crustaceans. Analysis of light and electron micrographs suggest that in specimens of C. fenneri from the Gulf of Mexico a single reproductive season exists.

In the male, the testis and vas deferens is much reduced in size and contain primarily spermatogonia and sustentacular cells during the late spring and summer months. Beginning in September - October numerous acini of the testis become filled with spermatocytes in various phases of meiosis. As the season progresses the acini become filled with more advanced stages of spermatogenesis until they become filled with mature sperm in January - February. While it is possible to see a few acini with different stages at all times, most of the acini contain more advanced stages with progression of the season.

The anterior portion of the vas deferens contains some spermatophores at all times. However, beginning in January it begins to swell. By March the middle and posterior regions of the vas deferens become swollen with seminal products as well. The anterior vas deferens produces the wall of the spermatophores which then become surrounded with seminal fluids produced in the middle vas deferens. As the number of spermatophores increases in the

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anterior region, some may also be seen in the middle region. The posterior region of the vas deferens produces an additional seminal product which is added to the contents of the anterior and middle regions at the time of copulation. Copulation appears to occur during March and April after which the reproductive tracts return to the reduced size seen during late spring and summer.

The spermatophores of Chaceon fenneri contain several sperm. These are typical brachyuran sperm with several small and long nuclear arms. The wall of the spermatophore differs from that of most brachyurans in having two layers. No noticeable difference can be observed between sperm of C. fenneri and C. quinquedens.

The fully developed ovary of the female is purple in color. Mature females begin oviposition in September - October. They release their larvae during February - March. This suggests an approximate six month brooding period. Females with developing broods will have ovaries of various size and color indicating that vitellogenesis takes place concurrently with embryonic development of the eggs in the brood pouch.

Other females collected during the late winter - spring months also exhibit ovaries at various stages of development. The seminal receptacles of mature females appear small in size from May to February. Swollen seminal receptacles have been found in females with hatching embryos or egg membranes attached to their pleopods. Females with ovaries in the early stages of development also appear to have swollen seminal receptacles at this time. Analysis of the contents of the swollen receptacles showed quantities of a translucent material as well as a white aggregate. The translucent material resembles that of the posterior vas deferens and the white aggregate contains sperm. In April and thereafter, the translucent material disappears from the seminal receptacle although the sperm persist. These sperm are retained until oviposition.

These data suggest that 1) females may mate following the molt to maturity and that then ovarian development commences and continues in these females until the time of oviposition or 2) females are capable of mating in the hardened condition following larval release. It would seem that females might be reproductive for several seasons. The number of barnacles attached to, as well as wear, to the edges of the carapace tend to support this premise. No eggs or egg cases were found on any females collected during April or May.

The progressive changes seen in both males and females of Chaceon fenneri thus suggest but a single breeding season.

AN ASSESSMENT OF THE GEORGIA GOLDEN CRAB FISHERY

Drew Kendall[16]

Crabs belonging to the genus, Chaceon, are non-swimming upper continental shelf inhabitants of the world oceans. To date, approximately 20 species have been identified, and it is likely that more will be discovered. Species reported off the United States in the Western Atlantic and Gulf of Mexico include the red crab, Chaceon quinquedens and the golden crab, Chaceon fenneri (Manning and Holthius 1984).

Golden crabs are known to range from South Carolina down the Atlantic Coast of Florida and into the Gulf of Mexico. Although some information regarding red crab biology and exploitation is available, data concerning the golden crab is limited. As a result, the Georgia Sea Grant Program initiated an assessment of this resource.

Eight cruises were made between November 1986 through October 1988 aboard the R/V Georgia Bulldog. This vessel is a 22 meter wood hull shrimp boat which is equipped with a topside mounted longline reel, and an extensive array of electronics.

Basic longline techniques were used to set out the traps. Fish carcasses were used for bait. Soak times were generally 20 hours.

Thirty six sets containing 612 traps were made. Yield from 577 recovered traps was 3025 kilograms of whole golden crabs. Average catch per trap was 7 kilograms. Approximate weight per crab was 0.9 kilograms. The only other animal caught in significant quantities were jonah crabs, Cancer borealis.

Golden crab sexes are distinct. Males are larger and possess a narrower shaped ventral apron. Our data also indicate segregation by sex. A total of 3176 crabs were sexed and measured. These animals were recovered in depths ranging from 240 to 490 meters, average depth about 366 meters. Eighty (2.5%) of these animals were female, and the remainder 3096 (97.5%) male.

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[16]Georgia Sea Grant Extension Program

Carapace widths were measured in a similar manner as with blue crabs, *Callinectes sapidus*. The size range was 75-195 mm, mean 151 mm, standard deviation 20 mm, and the mode was 160 mm. Assuming that small crabs and females are not trap shy, and that crabs recruit to the gear at 75 mm, this data seems to indicate an old population comprised of multiple year classes. Determination of the number and age of these classes is difficult, since data regarding the golden crab are lacking. However, studies on other species of *Chaceon* crabs, particularly the red crab suggest that this is an old slow growing population.

An attempt to determine the population density of golden crabs in two areas subjected to continuous fishing pressure was made. A removal method was employed in an effort to accomplish this. The results of this endeavor showed no significant change in crab catch over the course of 3 sets. In fact, catch rates and carapace widths remained almost the same from one set to the next.

There are several possible reasons for this. The most plausible explanation is that golden crabs are drawn to baited traps from a considerable distance. Given the desolate nature of this habitat it may be essential to the crab's survival that it possess the ability to locate food in remote locations, and move towards it.

In conclusion, the potential for developing a commercial fishery for golden crabs off the Georgia Coast is minimal. Long distances to the fishing grounds, uncertain markets for the crab product, and the hostile nature of working in the Gulf Stream pose obstacles which may be difficult to overcome.

RESPIRATORY AND CARDIOVASCULAR PHYSIOLOGY OF
CHACEON FENNERI AND C. QUINQUEDENS
IN NORMOXIA AND HYPOXIA

R.P. Henry, H.L. Handley, A. Krarup, and H. Perry[17]

Individuals of C. fenneri and C. quinquedens were maintained in 30 gallon aquaria in 35 parts per thousand seawater held between 5 and 10 C. Prior to experiments animals were fitted with electrodes and catheters and allowed to recover for 24 hours. Small diameter holes were drilled in the carapace on either side of the heart and scaphognathite, and copper wire electrodes were implanted using cyanoacrylate glue and a rubber dam. These were connected to an impedance converter and oscillographic recorder in order to monitor heart rate (HR) and the frequency of scaphognathite beating (Fscaph, ventilatory rate). A catheter was also implanted in a hole drilled in the branchial chamber; it was connected to a pressure transducer and recorder in order to measure branchial chamber pressure (Pbr) during ventilation. Animals were placed individually in 5 L plexiglas flow-through respiratory chambers, and oxygen uptake (VO^2) was measured as the difference between incurrent and excurrent 0^2 concentrations in the water. Heart rate, ventilatory frequency and pressure were measured simultaneously.

In normoxia (140-150 torr) respiratory and cardiovascular values were as follows:

	VO^2 umol 02 gm-1 min-1	HR bts min-1	Fscaph bts min-1	Pbr cm H20
C. fenneri (N=5)	0.0023 ± 0.0005	35 ± 3	28 ± 7	-1.1 ± 0.3
C. quinquedens (N=4)	0.0050 ± 0.0008	38 ± 1	99 ± 9	-1.5 ± 0.2

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Ventilatory pauses, characterized by a temporary cessation of scaphognathite activity and hart beat, which are common among many crustaceans, were observed for both species, but they were infrequent. Ventilatory reversals, during which the direction of water flow through the gill chamber is reversed, were also observed occasionally.

The water in the chamber was made progressively hypoxic by bubbling nitrogen through the incurrent channel. As water PO^2 decreased to about 70 torr, both species maintained near normal respiratory rates primarily through hyperventilation. Below 70 torr VO^2 decreased until a critical low PO^2 was reached at which respiration, ventilation, heart rate ceased (25-35 torr for *C. fenneri*, and 10 torr or less for *C. quinquedens*). Recovery of *C. fenneri* after the chamber was flushed with normoxic seawater took approximately 3 hours and was characterized by increased VO^2, hyperventilation, and tachycardia. *C. quinquedens* recovered much more quickly (usually by 1 hour), and the changes in VO^2, Fscaph, and HR were much less pronounced during that time.

In a second series of experiments pre- and post-branchial hemolyph samples (corresponding to venous and arterial samples) were taken from crabs in normoxia, hypoxia, and recovery, and hemolymph PO^2 was measured. The values for both species are given below:

	Post Branchial PO^2 (torr)	Pre Branchial PO^2 (torr)
C. fenneri (N=5)	88 $\pm$ 6	32 $\pm$ 6
C. quinquedens (N=4)	63 $\pm$ 16	21 $\pm$ 10

The arterial-venous difference is maintained in *C. fenneri* exposed to hypoxia down to a value of approximately 70 torr; below that it is reduced to about 2 torr. A similar pattern exists for *C. quinquedens* with the exception being that the arterial-venous difference remains higher (4-13 torr) even under extreme hypoxia. It also appears that *C. fenneri* experiences an oxygen debt in hypoxia, especially at the critical low PO^2 at which it ceases respiratory and cardiovascular activity. Hemolymph lactic acid concentrations more than double (0.76 mM to 1.5 mM) during hypoxia and remain elevated (~2 mM) during most of the recovery period. This does not appear to be the case for *C. quinquedens*. This animal maintains respiratory activity to a lower critical PO^2, maintains a higher arterial-venous difference in hemolymph PO^2 in hypoxia, and shows no significant lactic acid buildup in the hemolymph either during hypoxia or recovery.

In summary, it appears that C. quinquedens is somewhat more tolerant to hypoxia than is C. fenneri. Both species exhibit responses to hypoxia that are typical of crustaceans in general, and which relate more to common body form and morphological characteristics shared with other species than to any specific environment. Neither species appears particularly tolerant or well adapted to hypoxia, but neither do they appear overly sensitive. Both species are remarkably similar to shallow water species with regard to respiratory and cardiovascular adaptations.

RAPPORTEUR'S COMMENTS

COMMENTARY ON CRAB MANAGEMENT AND THE EAST COAST UNITED STATES GERYONID FISHERIES

David A. Armstrong[18]

Crab fisheries comprise some of the richest resources harvested along the United States coastline. In 1988, total landings exceeded 455 million pounds worth over 383 million dollars (NMFS, 1989), and equaled about 25% of the total dollar value of all U.S. invertebrate fisheries. Crabs harvested in the United States comprise some of the most interesting life history, ecological, and reproductive characteristics to be found among managed U.S. species, and yet the nature and extent of management tends to be relatively similar despite great variation in life history patterns.

The geryonid crab conference, convened in January 1989, considered a variety of life history and ecological data for two principal species, Chaceon quinquedens and C. fenneri, and discussed this information in light of the fledgling deep-water crab fisheries situated in the South Atlantic Bight and northeastern Gulf of Mexico. In general, participants at the conference were not overly optimistic about the prospects for large and sustained fisheries for these species because of their deep-water distribution, evidence of infrequent recruitment, slow growth, older age at reproductive and legal size, and fairly low density over extended regions of the species' range.

As background to analysis of Chaceon biology and life history characteristics relative to their fishery potential, a brief overview of other U.S. crab fisheries can serve to highlight approaches used in management for species that vary considerably in their life history characteristics. Many points of contrast and similarity have been reviewed by Jamieson (1986) who divided crab fisheries into nearshore shallow-water species such as Cancer and Callinectes, and deep water offshore species such as Paralithodes and Chionoecetes. In addition to this bathymetric and on/offshore distinction, it is also informative to distinguish crab fisheries based on the extent of management which ranges from fairly passive (e.g. Cancer magister, Chaceon maritae) to highly dynamic (e.g. Paralithodes camtschatica and Chionoectes bairdii).

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Other U.S. Crab Fisheries

In the temperate to subarctic latitudes of the western U.S. there are three principal crab fisheries. The Dungeness fishery ranges from central California to southeast Alaska, and the king and Tanner crab fisheries largely occur in the Gulf of Alaska and southeastern Bering Sea (Table 1). The latter two groups, king and Tanner crab, are extensively and dynamically managed through joint jurisdiction shared by the state fisheries department and the National Marine Fisheries Service (NMFS). As in the case of most crab fisheries, much of the management is directed toward providing safeguards for reproductive effort by excluding females from the fisheries and setting minimum sizes to allow for adequate male reproduction before capture by the fisheries. This tends to highlight a relatively conservative approach to crab management in the sense that no spawner-recruit relationships have been demonstrated for any species of crab in U.S. waters, and this point was emphasized by several of the participants at the workshop for Chaceon as well. Noticeably different about the management approach to king and Tanner crab is the extensive preseason survey undertaken annually by NMFS that results, eventually, in "harvest range" guidelines as the basis for a strictly managed quota system (Otto, 1981, 1986; NPFMC, 1988). Despite prohibition against capture of females, limited fishing seasons (as short as several weeks in the case of king crab), and extensive survey estimates that lead to imposition of quotas, landings for both king and Tanner crab have fluctuated substantially over the last 15-20 years (Table 1). The fisheries for these long-lived species (8-10 years of age for entry in the case of king crab, 6-8 years for Tanner crab) seem dependent on relatively uncommon, strong year classes, and year-class strength is otherwise viewed as dependent on a suite of physical and biological factors that generally lead to poor survival of larvae or young juveniles (see numerous review articles in Alaska Sea Grant Symposia for Tanner crab, 1982; king crab, 1985 and Dungeness crab, 1985).

Dungeness crab is fished extensively from California through British Columbia to southeast Alaska and, over much of its range, has been characterized by a trend of relatively constant cycles of high and low abundance (see reviews by Botsford, 1986; Botsford et al., 1989; Methot, 1989). Management of this species is relatively passive and carried out by state fisheries agencies throughout its range. This approach prohibits capture of females, imposes a minimum size limit of about 165mm carapace width (CW) and enforces a season closure from fall to early winter (Table 1). No preseason survey exists to estimate abundance of Dungeness crab, nor is there

Species	Sex Fished	Size Limit (mm carapace width)	Estimated Minimum Age in Fishery (YR)	Season Closure	Pre-Season Survey	Gear	Range of Landings (over last 15 yrs) (lb x 10^6)	Quota	Comment
Red King Crab[1] (*Paralithodes camtschatica*)	M	165	8-10	Yes	Extensive	Pot	3-130 Bering Sea	"harvest range" guidelines	
Tanner Crab[2] (*Chionoectes bairdi*)	M	140	6-8	Yes	Extensive	Pot	47-146 all Alaska	"harvest range" guidelines	
Dungeness Crab[3] (*Cancer magister*)	M	165	3-5	Yes	Virtually None	Pot	16-60 Cal-Alaska plus British Columbia	None	Pre-season survey for male shell condition only
Blue Crab[4] (*Callinectes sapidus*)	M, F	75-125	2	Yes; variable between states	No	Pot, dredge, trawl, trotlines	40-104 Chesapeake Bay	None	
Stone Crab[5] (*Menippe mercenaria*)	M, F	claws only, propodus >70	2-3	Yes	No	wooden trap	0.5-3.0 Florida	None	
Red Crab[6] (*Chaceon maritae*)	M, F	None gear 100% selective for crab >75mm	6-8	No	No	Pot	7.7-13.1 SW Africa	None	Japanese fishery off SW Africa; age of catch estimated to be between 8-16 yrs. of age
Golden Crab[7] (*Chaceon fenneri*)	M, F	None	?	No	No	Pot	?	None	

[1]Otto 1986; NPFMC 1988
[2]Otto 1981; NMFS Fisheries stats 1983-88, Alaska Sea Grant 1982
[3]Alaska Sea Grant 1985; PMFC 1987
[4]Millikin and Williams 1984; Jamieson 1986; Cronin 1987
[5]Ehrhardt and Restrepo 1989
[6]Melville-Smith 1988
[7]Workshop Participants

Table 1. Representative crab fisheries and comparison of major features of management and landings.

a quota system. All animals of legal size are vulnerable to the fishery and indeed many states are highly dependent upon annual recruitment to the fisheries for the bulk of landings. Despite threefold fluctuations in apparent abundance (more exaggerated in certain states such as Washington where landings have gone from approximately 4 million pounds in 1985 to over 20 million pounds in 1989), populations are not generally viewed as unstable, and such fluctuations in abundance are credited to a variety of physical oceanographic or biological impacts (see review by Botsford et al., 1989).

The dominant crab fishery on the eastern and Gulf coast of the United States is that for blue crab (Callinectes sapidus). This is a fairly complex fishery from a jurisdictional standpoint since in the area of the Chesapeake Bay, several states manage the resource and yet have variable management approaches concerning legal size, season and gear of capture (Table 1). Both males and females may be captured and, at times, even ovigerous females are legal in certain states. As a relatively short-lived species (2 years at legal size), C. sapidus has proved to be a useful model of recruitment variability as explained by physical and biological features of its habitat (e.g. see review by Sulkin and Epifanio, 1986). A range in landings of about 2.5 fold in Chesapeake Bay has been explained by variability in larval recruitment due to features of wind and current transport that affect attendent larval behavior, and the extent and nature of optimal juvenile habitat within Chesapeake Bay.

A unique fishery located in the southeastern United States is that for stone crabs, Menippe mercenaria and M. adina, which is based not on the whole body of the animal as in other crab fisheries, but only on the extremely large chelipeds. This fishery, located primarily in Florida, allows capture of both sexes and requires a minimal claw size of 70mm propodus length. This equates to an age of about 2-3 years depending on sex and is further managed by a closed season designed to essentially protect female reproduction (Table 1; Ehrhardt and Restrepo, 1989). From the 1970's, catch increased from about a quarter to 3 million pounds of claws annually, but has declined somewhat in recent years.

In the case of these species, relatively extensive literature exists on aspects of life history, reproductive biology, general ecology and habitat requirements. Yet despite commercial importance as fisheries - sometimes for many decades - a surprising amount of information is still unknown about patterns of larval transport, habitat requirements as related to potential year class strength, and any spawner-recruit relationship between mature females and any index of juvenile year class success. While not all such information is needed to manage fisheries, biologists are nonetheless often hampered in their interpretation of fluctuations and apparent population abundance because of too little knowledge of many aspects of species biology; eastern United States species of the genus Chaceon represent an acute example of this situation.

Geryonid Crab Fisheries

Before reviewing information concerning eastern U.S. species of Chaceon, it is important to consider biological and fisheries information from the southwest African fishery exploited by the Japanese and targeted on C. maritae (Melville-Smith this proceeding, 1988). This fishery is relatively new, since about 1973, and has been exploited along the southwestern African coast without benefit of management practices. It is essentially driven by economic considerations relative to the size of product that can be economically processed, and the extent of fishing effort deemed feasible and profitable by Japanese fisheries companies.

Several aspects of the species' life history have important bearing on trends in the current fishery data. As is the case with many geryonid crabs, it is a deep-water species distributed from a couple of hundred to 700m in waters that can range from 4.5 to 10.4°C. As a consequence, it is very slow growing and reaches sexual maturity between 7-9 years of age. Both males and females are fished and are susceptible to the fishery from age 7-9, but many may range from 10-16 years of age (Melville-Smith, 1988). Females are mature at a size of 84mm CW but this size may reflect fishing pressure since maturity in unexploited populations was estimated to be about 100mm CW. One dilemma faced by the fishery is that Japanese pot gear uses a 90mm mesh dimension which is 100% selective for crab greater than 75mm CW, about 9mm smaller than the size at sexual maturity (Melville-Smith this proceedings, 1988). Melville-Smith believes that fisheries over much of the range of C. maritae have come to rely excessively on prerecruits of a given year class reaching legal size in a single year. Since the fishery captures such a large portion of females prior to maturity, and since a very small fraction of the female population is ovigerous at any point in time (0.1 to 0.2%; Melville-Smith, 1988) he fears the combined effects may severely impact egg production and consequently larval transport to heavily fished areas off the southwestern African coast. As evidence of this concern, total Japanese landings have declined from 5.97 million kg in 1983 to 4.72 million in 1986. Based on catch rate CPUE, Melville-Smith estimated that the density of Chaceon on African fishing grounds has decreased about 26% over the past six years (Melville-Smith, 1988).

Such trends of decreasing abundance and catch rate in the South African fishery portend negative consequences for the eastern U.S. fishery for Chaceon as well, with potentially more dramatic consequences based on relative densities of the two species. Density of C. maritae has been estimated to range from 40-230 crab/ha based on pot sampling, up to 350/ha based on observations with underwater photography (Melville-Smith, 1985). However, density of both C. quinquedens and C. fenneri, over much of their range along the eastern U.S. and into the Gulf of Mexico has been estimated to be substantially less, although little density information is available. Lindberg (this proceeding) estimated a standing stock of C. fenneri off Florida's Gulf Coast to be about 7.8 million crab (about 13.6 million pounds). Wenner (this proceeding) observed densities of only 1.9/ha from submersible observations of C. fenneri. However, Whitlatch (this proceeding) reported densities of C. quinquedens up to 900/ha off the southern New England coast, and Wigley et al. (1975) estimated densities of 130-380/ha along the shelf of northeastern U.S. Over a distance of more than 700 km they estimated a standing stock of about 43 million commercial size crab (114mm, 4.5 inches CW) which equated to about 59 million pounds total weight.

It seems that estimates of abundance of surplus males greater than 114mm CW suggests the potential for a sustained fishery on C. quinquedens in the area from Maryland to Georges bank. However, since the survey by Wigley et al. (1975) there have not been sufficient studies to indicate whether juvenile recruitment is consistent on an annual basis, the magnitude of natural mortality rates (Melville-Smith, 1988, provides estimates for the African species) and, in turn, estimated survival to legal size. As in the case of king crab in the Bering Sea, it may be that Chaceon is typified by relatively infrequent, strong year classes that could be overly exploited by a directed, open (no harvest quota) fishery.

Fisheries prospects for C. fenneri, the golden crab, in the South Atlantic Bight to the Gulf of Mexico are more tenuous. The species seems distributed at very low densities but has the capacity to locate food and traps over an apparently great distance (Wenner this proceeding, Wenner et al., 1987) which portends rapid depletion in areas heavily fished. Given aspects of both species' life history (reviewed by Hines and others this proceeding) such as deep water distribution at cold temperatures, slow growth and relatively advanced age at maturity and legal size, it seems that high sustained yield is not likely. As in the case of other crab fisheries listed in Table 1, managers could take a conservative approach (as apparently has been done) that allows capture only of males of a size and age beyond reproductive maturity, with the objective of maintaining species reproductive effort quite apart from the knowledge of biotic and abiotic factors that affect year class strength.

In order to provide some likelihood of reasonable annual catch by participating fisherman, managers may want to consider a limited-entry fishery as has been done with a number of Australian invertebrate species. Given the expense of capitalization for such deep water fishing, it seems that fishermen are vulnerable to the vagaries of surplus male abundance which could be quickly reduced by unrestricted participation. Without an annual preseason survey and resultant catch quota at the present, there is no basis to attenuate excessive annual exploitation and spread capture of large males over several years, particularly if year classes reaching legal size are infrequently strong as hypothesized for P. camtschatica in the Bering Sea. Limited entry (and effort) might achieve this goal of more stable yield, although somewhat blindly since state fisheries agencies will likely not conduct surveys to estimate stock abundance as a means to index the degree of annual exploitation by a limited-entry fishery.

Another option as practiced for some west coast Canadian invertebrate fisheries that are not well studied and regulated is that of "boom and bust". So long as rudimentary guidelines safeguard reproductive effort, the fishery is allowed to grow to any size (unrestricted vessel participation) and achieve 100% exploitation as it is able. Eventual decrease in abundance and reduction in landings are consequences to which fishermen must adjust as they either stay with Chaceon spp. or move into other fisheries. Clearly the southwestern African C. maritae fishery is precarious because management guidelines have not been implemented to even safeguard reproductive effort through size, sex and season. In comparison, U.S. Chaceon fisheries can be better managed, but species recruitment success and population dynamics might be such as to provide only a limited and marginal fishery off many states.

RAPPORTEUR'S COMMENTS

Commentary on Life History and Ecology of Deep-Sea Crabs of the Family Geryonidae

Anson H. Hines[19]

Successful management of fisheries sustaining maximum yield requires strategic decisions from accurate knowledge of the basic life history and ecology of target species. In addition, prediction of the impact of fishing activities on the ecosystem depends upon knowledge of the fundamental role of the species in its natural community. For crabs of the family Geryonidae, development of a data base which will allow informed management decisions is inherently difficult because of the depth distribution of the species on the continental slope. Nevertheless, fisheries are developing for geryonid species, and we need to assess our knowledge of their basic biology. In addition, as manned and remotely operated technology has developed, we are increasingly able to examine the importance of these crabs in the continental slop ecosystem as a zone of both fundamental and applied interests.

The workshop on geryonid crabs was convened to assess the state of our knowledge and research progress on primarily two species, Chaceon quinquedens and C. fenneri (the genus of these two species was revised in 1989 from Geryon to Chaceon, see below under Systematics). However, a comparative approach in the workshop emphasized similarities and contrasts among these two species and other members of the family, as well as species of commercial and non-commercial crabs from other families. This readily allowed both scientists and managers to organize data into meaningful patterns, to assess the unique and general features of the particular species, to benefit from the mistakes and successes in management of other species, and to establish research priorities. The workshop also emphasized the need for comparative data over the geographic range of the species, because these contrasts provide insight into the variability and flexibility of the species' biology.

In addition to assessing the systematic and zoogeographic status of the family Geryonidae, considerations of life history and ecology were organized into several subtopics. The topics within life history analysis fell into the sequence of the crabs' life

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cycle of reproduction, development, growth, and maturation. As these topics are aspects of population biology, they led logically into considerations of population stability, dispersal, resource utilization, and sources of mortality. The workshop also considered the crabs' potential as regulators of benthic community structure on the continental slope. The purpose of this commentary is to summarize the discussion, emphasizing the participants' concensus about what is and is not known about the basic biology of the crabs, but it is not meant to provide a comprehensive review of the geryonid literature.

Systematics and Zoogeography. Initially, very few species were thought to comprise the Geryonidae; however, in a recent revision of the family, three genera and 24 species (Geryon with two species, Chaceon with 21 species including C. fenneri, C. quinquedens and C. maritae, and Zariquieyon with one species) are now recognized (Manning and Holthius, 1989). The number of recognized species is likely to increase with additional attention by systematists, ecologists, and fisheries biologists and with new technological applications at more sites. Some of the characters used to distinguish species include phenotypic features, especially color, which some workshop participants believed were too variable within species to be reliable diagnostic characters. On the other hand, the shape (lateral compression vs. dorso-ventral depression) of the dactyls of the walking legs is apparently both a useful diagnostic character for some species and a potential indicator of primary substrate utilization (see Resource Utilization below). The family is apparently widely distributed throughout the world's oceans at depths of 200-1200 m, especially on upper continental slopes. Although some species are small in body size and, through limited sampling, are known only from very restricted geographic ranges, the large size, abundance and distribution of some species indicate that the family plays an important role in the slope ecosystem on a world-wide basis.

Reproduction. Several recent studies have focused on reproduction in Chaceon spp. (Melville-Smith, 1987; Wenner et al., 1987; Hinsch, 1988a,b; Erdmann and Blake, 1988; Hines, 1988), following initial survey work by Haefner (1977) and McElman and Elner (1982). Gametogenesis is similar to that in other species of crabs. Chaceon maritae reproduces year-round, and C. quinquedens exhibits low levels of brooding year-round. However, off New England and Florida C. quiquedens apparently has a winter peak in brooding, and C. fenneri is a distinctly seasonal winter brooder off Florida. Individual females of any of the three studied species probably do not produce more than one brood per year. Also, some evidence indicates that individual brood production may be biennial in C.

fenneri (see Maturation and Mating below). Compared to other species of crabs, egg size in Chaceon spp. is very large, and fecundity is relatively low (100,000 - 400,000 eggs per brood) for such large body size.

Development and Recruitment. Larval descriptions are available for C. quinquedens (Perkins, 1973), C. tridens (Brattegard and Sankarankutty, 1967; Ingle, 1979) and C. fenneri (Perry, pers. comm.). Experiments on C. quinquedens in laboratory culture indicate that these larvae have long developmental times in cold waters (125 days at 6-10°C) but much shorter times at temperatures typical of warmer surface waters (only 23 days at 25°C) (Rosowski, 1979; Sulkin and Van Heukelem, 1980; Kelly et al., 1982). The larvae exhibit considerable "nutritional flexibility" in their ability to develop normally even on relatively poor quality food such as rotifers (Sulkin and Van Heukelem, 1980), perhaps as a result of the large amount of yolk invested in the eggs (Hines, 1988). The larval biology of deep-sea crabs is poorly understood because so few zoeae and megalopae have been sampled in the field (but see Roff et al., 1984, 1986). However, the lab experiments and the few larvae collected in the plankton indicate that development occurs near the surface, as is typical of most crabs. Laboratory studies of larval responses to temperature, pressure and gravity indicate that larval C. quinquedens can migrate vertically through the water column with swimming behavior that allows them to pass through marked thermoclines, which is adaptive for moving early stage larvae up to the warmer, food-rich surface waters and for producing wide larval dispersal in surface currents (Kelly et al., 1982).

Very few small crabs have been collected or observed in the field; and the timing, habitat, and intensity of recruitment are poorly understood. The few small crabs which have been found come from the deepest zones of the species distribution for C. quinquedens and C. fenneri (Wigley et al., 1975). We need to test quantitatively the validity of this observation by trying to determine whether the lack of small crabs observed via submersibles (Lindberg and Lockhart, 1988) and their paucity from trawls is typical, or whether our sampling designs have been inadequate. We need to know whether recruitment is specific to greater depths, or whether recruitment occurs at all depths and small crabs suffer higher mortality at shallower depths.

Growth. Deep-sea crabs appear to be slow growing, long-lived animals. In some cases (e.g., female C. fenneri off the South Atlantic Bight of North America; Wenner et al., 1987), populations exhibit polymodal size-frequency distributions; but it is not known if these modes correspond to year-classes or instars. If the modes are instars, then the number of instars is not unusually large but the molt increment is substantial (40-50% for 100 mm crabs declining to about 14% for 145 mm crabs). If the modes are year-classes, then these are estimates of annual growth but they tell us nothing about the number of instars, although the occurrence of annual molting in females would equate number of post-maturation instars and years (but see Maturation and Mating below). Most populations, especially males, show no polymodality in size structure. Size-frequency analysis of all populations of C. quinquedens, C. fenneri, and C. maritae do show that males grow substantially larger (about 50% carapace width) than females.

Other things being equal, large size at settlement will reduce the time and number of instars required to grow to maturity (Hines, 1986). Size at settlement of the first crab instar is unusually large (4 mm carapace width in C. quinquedens, Van Heukelem et al., 1983, and 3 mm in Geryon tridens, Ingle, 1979) compared to most crab species and is similar to the large first crabs of Ocypode spp. and Cancer magister (Hines, 1986). This large size at settlement may be adaptive for otherwise slow growth to adult size.

Growth has been measured directly in C. maritae (Melville-Smith, 1989) and C. quinquedens (Farlow, 1980; Gerrior, 1981; Lux et al., 1982; Van Heukelem et al., 1983). Farlow (1980) reported molt increments of 8-21% for captive 73-94 mm female C. quinquedens, with no correlation of increment and premolt size. Limited data from field tagging studies of C. quinquedens indicate slow growth and potentially long intervals (perhaps 6-7 yr or more) between molts of larger crabs (Gerrior, 1981; Lux et al., 1982). In C. quinquedens reared through the first 5-6 juvenile instars (about 20 mm carapace width) from larvae in the lab, growth rate was temperature dependent and indicates that 5-6 years would be required to grow to entry into the fishery at 114 mm or about 7-8 years to maximum size of 140 mm (Van Heukelem et al., 1983). In the best analysis of growth in a geryonid, Melville-Smith (1989) used dart tags in epimeral sutures for a mark-recapture study of C. maritae to determine the molt increment and estimate intermolt interval in crabs >60 mm. The molt increment percentage declines with increasing size from about 20-25% at 60 mm to about 15% at 130 mm. Males had larger molt increments than females, and males exhibited a reduced molt increment after maturity at about 93 mm. Females molted only rarely after attaining maturity. Estimated molt intervals for males ranged from about 1.5 yr for 60 mm crabs to 6-7 yr for 130 mm crabs. By combining the laboratory data for early instars of C. quinquedens with the field data for C. maritae, Melville-Smith (1989) estimated the size and age of each instar for

C. maritae, with male maturity occurring at 12 instars, 90 mm, and 9 yrs of age, and maximum growth to 170 mm requiring 16 instars and 33 yrs. Although these estimates for intermolt interval and age are indeed long, some other cold-water species (Chionoecetes spp. and Cancer pagurus) are also estimated to have similar slow growth and long life. The number of instars and molt increments reported by Melville-Smith (1989) for C. maritae are typical for most brachyurans (Hines, unpublished).

Maturation and Mating. Based on growth studies, mature crabs are 5-15 years old or more. Both sexes appear to mature at about the same size, but males grow larger than females. Maturation occurs at about 90 mm in C. maritae, 95 mm in C. fenneri, and 85 mm in C. quinquedens. Although some workshop participants suggested that females exhibit a terminal molt at maturity but males do not, there is no real evidence to indicate a true terminal molt (see recent dispute over this issue for the majid crab Chionoecetes opilio: Conan and Comeau, 1986; Ennis et al., 1988; Donaldson and Johnson, 1988), though molting may be very infrequent (6-7 yr). In C. maritae, mature females have been observed to molt, but it appears that they do so only rarely (Melville-Smith, 1983). Maturation may occur seasonally in C. fenneri and C. quinquedens, which have populations with seasonal reproductive cycles; and maturation may occur all year round in C. maritae, which reproduces year-round. There are few data to test these proposed seasonal patterns.

Because the two sexes of many populations appear to differ in their bathymetric distributions (see below under Resource Utilization), it is not clear how the sexes get together for mating. A seasonal vertical migration by females has been postulated (e.g., Wigley et al., 1975), but little hard evidence is available. Males probably are attracted to mates by pheromones released by the female, as is the case in many other decapod crustaceans including many brachyurans; and based on observation of chemotaxis to bait, the chemotaxis could operate on the scale of tens of meters in appropriate current regimes (Lindberg, pers. comm.).

Observations in the laboratory indicate that mating behavior is typical of other crabs (Elner et al., 1987 for C. quinquedens; Mori and Relini, 1982 for C. longipes; Wenner et al., 1987 and Perry, pers. comm. for C. fenneri) but that doubling up and intromission may last for a long period (11.5 days in C. quinquedens and weeks or more in C. fenneri in the laboratory). Males apparently may mate with intermolt females as well as copulating with newly molted females. With post-copulatory marking analogous to those on Dungeness crabs (Cancer magister) and snow crabs (Chionoecetes opilio), female Chaceon maritae show abrasions on their walking legs from mating embraces, as well as darkened vulvae and abrasions from contact with male pleopods on the ventral carapace under the abdominal flap (Melville-Smith, 1987). While categorization of female vulvae does indicate maturation and mating in other Chaceon spp. (e.g., Wenner et al., 1987), similar mating marks have not been recorded for female carapaces of other geryonids.

In C. fenneri there is controversy over whether females molt and mate annually (Hinsch, 1988a,b) or molt after a brood is released and mate later to produce the next brood in alternate years for a biennial reproductive cycle (Erdman and Blake, 1988; Erdman, in review). Precedent occurs for such a biennial cycle in cold-water for the blue king crab Parlithodes platypus (Jensen and Armstrong, 1989). Obviously, reproduction could occur within the population each year; but with only half of the females producing a brood, the population's egg production would be only half of that if all females brooded annually. As in some other groups of crabs, females may store sperm for prolonged periods, producing one or more broods without additional copulation. However, there are few data to test this, and no one knows if sperm can be stored by a female from one instar to another. Some of these reproductive strategies may be highly adaptive for cold, food-poor waters of the deep sea, where energy for yolk accumulation may be difficult to acquire; and they may also serve to ensure reproductive success when mates are difficult to find.

The length of reproductive life in geryonids is not known, but life spans of up to 33 years have been speculated. No evidence of senility has been found, but most population samples provide too few females to yield adequate analysis of reproductive activity by size (age). Mature males appear to be equally reproductive at all sizes.

Population Stability and Dispersal. Although population densities, sexual composition, and size structure appear to vary significantly in space for C. fenneri, C. quinquedens, and C. maritae, we have very little real data on annual or long-term variation in population abundance. Because of the potential for long-distance larval dispersal, there is concern that recruitment for key fishery locations may depend heavily on reproductive stock under distant management jurisdictions. For example, recruitment for the C. maritae fishery off southwest African waters appears to be derived from stocks to the north. Similarly, Kelly et al. (1982) proposed that larval C. quinquedens are transported to the mid-Atlantic Bight by the Gulf Stream. Although recruitment is poorly understood in any geryonid species, failure to find many small juveniles and comparisons with recruitment fluctuations in blue crab (Callinectes sapidus), Dungeness crab (Cancer magister), snow crab (Chionoecetes opilio), and king crab (Paralithodes spp.) populations suggest that major successful recruitment events occur very rarely; but those recruits may dominate a population for a long period, perhaps 10 years or more.

Movement of some geryonids appears to be substantial and could cause significant dispersal. Despite apparently intensive trapping in some locations (e.g., the C. fenneri fishery off Ft. Lauderdale, Florida), there has been no apparent reduction in crab abundance, suggesting that other crabs are "filling in" from some unknown distance in the surrounding waters. Melville-Smith (1987) reports significant movement of C. maritae in mark/recapture studies off the coast of southwest Africa/Namibia, with differences between sexes. Mature females exhibited significant net movement northward and greater movement than other categories of crabs. Large males moved farther than small males. Over 32% of the recaptured crabs moved greater than 100 km over a period of years of the study. The net rate of movement was only about 0.05 km/day for males and immature females, while mature females moved 0.11 km/day southward compared to 0.46 km/day northward. These movement data may indicate a sexual pattern of migration off the African coast. Lux et al. (1982) found that most net movement was under 20 km for C. quinquedens off southern New England, although some individuals moved as far as 90 km during a 7 year study period. No evidence of seasonal migration was found, and most movement appeared to be up and down the continental slope rather than long-shore.

Stock identification is poorly understood for geryonid fisheries. Because of the potential for wide larval dispersal and substantial benthic movement of juveniles and adults, there is little understanding of any barriers that would serve to delineate biologically appropriate management boundaries or to provide clues about deme size and gene flow. Population size of C. maritae off southwest Africa has been estimated by photography and tagging to be 21.6 and 19.5 million crabs respectively, while trawling underestimates population size at 1.9 million crabs (summarized in Melville-Smith, 1988). Since early population estimates for other fisheries are largely based on trawl or trap data, little trust can be placed on those reports. More recent surveys from submersibles (Whitlatch, unpublished; Lindberg and Lockhart, 1988; Wenner and Barans, in press) give more accurate information for C. quinquedens and C. fenneri, but the geographic extent of those surveys is limited, making it inadvisable to extrapolate population size.

Resource Utilization (depth, substrate, food). Geryonids show habitat partitioning by depth and substrate. The majority of available data is for bathymetric distribution. Chaceon fenneri and C. quinquedens occur at different depth zones in the eastern Gulf of Mexico, with C. fenneri distributed shallower than C. quinquedens (Lindberg and Lockhart, 1988; Lindberg et al., 1989). In addition to interspecific zonation, most populations show intraspecific zonation with the two sexes distributed differently. For C. fenneri, C. quinquedens and C. maritae, females tend to be more abundant at shallower depths (Lindberg et al., 1989; Haefner, 1978; Melville-Smith, 1987), although the few females trapped by Wenner et al. (1987) in the South Atlantic Bight were deeper than most males.

Chaceon maritae, C. quinquedens, and C. fenneri are found patchily distributed on both soft and hard substrates. Chaceon quinquedens appears to be most common on soft substrates, while C. fenneri apparently reaches highest densities on hard substrates (Wenner and Barans, in press; Lindberg, pers. comm.). The laterally compressed dactyls of C. fenneri may be better adapted for hard substrates, while the dorso-ventrallly depressed dactyls of C. quinquedens may allow easier movement over soft substrates (Manning, pers. comm.). The association of these crabs with particular substrates is of particular interest to fishermen, who want to fish high density patches of crabs but must avoid hard substrates which might foul gear.

The diet of geryonids is poorly known. They are often categorized as scavengers that feed opportunistically on bonanzas of carrion deposited on the bottom from overlying waters. The only significant published analysis of stomach contents of crabs not captured in baited traps is by Farlow (1980) for C. quinquedens off southern New England, where the crabs are predators as well as scavengers. Small crabs fed mainly on sponges, hydroides, gastropods, schaphopods, small polychaetes, and small crustaceans; large crabs also took larger prey (including fishes, squid, and Hyalinecia) but it is not entirely clear if these items were scavenged or captured alive. Diel changes in gut fullness of crabs in the field indicate 1-2 peaks of feeding during daylight hours. Crabs about 250 g in weight consume 0.09-0.7 g dry weight of food per day, with much of the food mass as mucus and sediment that may be of little nutritional value. Observations of feeding behavior from submersibles indicates that C. quinquedens may be a deposit feeder to some extent, and that C. fenneri is attracted from considerable distances (tens of meters) by olfactory cues from bait.

Sources of Mortality. Few data are available on sources of mortality for geryonids. Several species of fish are reported to prey upon juveniles (Melville-Smith, pers. comm. for C. maritae), but there are few published records of geryonids in fish stomach contents (Sedberry and Musick, 1978 for the gadid Phycis chesteri on C. quinquedens). Mortality rates from fishing have been estimated at 0.24 males and 0.41 females per year (Melville-Smith, 1988). Other estimates of mortality are lacking.

Community Interactions: Deep-Sea crabs as Predators, Bioturbators, Competitors, and Hosts. Geryonids may have a significant role as a dominant predator in continental slope communities. Analysis of stomach contents for C. quinquedens indicates active predation on a wide variety of infaunal and epibenthic invertebrates (Farlow, 1980). Observations of C. quinquedens off southern New England (Grassle et al., 1975; Haedrich et al., 1975; Whitlatch, pers. comm.) and C. fenneri (Wenner, pers. comm.) off South Carolina indicate that these crabs are major sources of bioturbation in the surface sediments of the slope. Locomotion and active digging in addition to feeding activities appear to disturb and turn over the sediment extensively in areas where the crabs are relatively abundant.

Competition among geryonid crabs is poorly understood. Bathymetric partitioning by C. fenneri and C. quinquedens could result from competitive interactions between these two species in which goldern crabs exclude red crabs from shallower depths. However, C. quinquedens does not move shallower in areas where C. fenneri is absent in the Gulf of Mexico (Lindberg et al., 1989). Off New England, Cancer borealis and Homarus americanus may be competing with C. quinquedens at the shallow edge of its distribution. Although geryonids are not obviously aggressive in captivity, field observations of crabs approaching traps do show agonistic interactions with threat displays typical of other brachyurans (Lindberg, pers. comm.). Competition for mates is not known, but prolonged mating may serve to prevent multiple males from copulating with a female.

A variety of commensal species occur on geryonids, including stalked barnacles (Poecilasma spp.) and a polychaete Dorveillia geronicola on C. fenneri and C. quinquedens. Although the density and size of barnacles fouling a crab's carapace may be indicators of time since molting, too little is known about the biology of the barnacles to calibrate their rates of settlement and growth. Chaceon quinquedens and C. fenneri also have a high frequency of chitinolytic bacteria, which cause dark lesions on their carapaces. The frequency of lesions may also be an indicator of time since molting, but little is known about the time course of their development nor of their potential pathology.

EDITED GROUP DISCUSSION TRANSCRIPTS

W. LINDBERG: We would like to hear comments about what you heard yesterday and, based on your experience, what you think the particular needs of the fishery are. Dick, do you want to lead off?

D. NIELSON: I'm Dick Nielson, commercial fisherman in Fort Lauderdale, Florida. First of all, I'd like to thank the people who set up this workshop. I think it's very interesting to me as a commercial fisherman, and I'm very proud to be here. You have done a tremendous job bringing these people from all over the world to this workshop. I particularly love workshops, more so because every time we go before regulatory powers here in the State of Florida we normally have about three minutes to speak, and I've been given a lot more time than that today and I appreciate that, believe me.

Commercial fishermen here in Florida are certainly under a lot of pressure. I wrote down quite a bit of information here, but I've got it titled "Golden Crab Trapping" and it really should be "Last Frontier of Commercial Fishing in Florida." I look at the deep-water golden crab as a last frontier, and I'm very interested in harvesting it commercially.

It all started about three years ago. Howard Rau, a commercial fisherman who traps for lobster and fish, moved out to deeper waters off Fort Lauderdale in search of fish. In 700 feet of water he began to catch golden crab in his fish traps. Howard Rau was the first fisherman to land golden crab in the Fort Lauderdale area. When I received news that we had golden crab off our east coast, and tasted some crab from Howard which was excellent, I decided to design and build a trap that would catch them more efficiently. This was done through research and trap design literature from Alaska, Canada and the University of Rhode Island.

The trap had three-eighth inch rebar frame and five-inch nylon webbing mesh on the sides and top with a one and a half by one and a half plastic coated wire on the bottom. The trap had a double funnel entrance five inches high, 24 inches wide. The trap size is four feet by six feet by 30 inches high. Five traps 900 feet apart make up a trawl. Because of the Gulf Stream conditions, traps were retrieved by grappling.

A five-inch escape ring was installed at a later date to release females and smaller males on the bottom. Research on golden crab reproduction and spawning was done aboard my vessel. I highly recommend a working relationship between fishermen and biologists. When the time comes to regulate the golden crab, I want to help determine those regulations.

Three of us fishermen at this meeting have a proposal of regulations that we would like to see in place on the golden crab before we even really get into harvesting this crab on a larger scale. One of the first proposals would be an escape ring sized to release females and small males. I would like the scientists to tell us the most appropriate size. Secondly, we recommend no harvest of female crabs. We have never harvested female crabs. The female is a smaller crab, about half the size of the adult male, and we don't catch that many of them. We think it's much better just to leave that female crab on the bottom and help to preserve this resource. The third proposal would be a carapace measure for the male crab that would translate to about a pound and a quarter male crab. We would like to release anything below a pound and a quarter, also targeted by the escape ring. Once again, I leave the width of that carapace measure to be determined from scientific research that has been done. We can get together with you people and come up with some figures on that.

I certainly have enjoyed this two day workshop. It has been a pleasure being here and I certainly encourage more research. Any time the commercial fishermen of Fort Lauderdale can help in providing a vehicle for this research, we are more than happy to accommodate you. Thank you very much.

W. LINDBERG: Thank you, Richard.

D. ARMSTRONG: What is the approximate size, in inches, of an animal that weighs one and a quarter pounds?

R. ERDMAN: About 125 to 130 millimeters.

G. HINSCH: If you look at the size range at which they seem to be reproductively mature, the smaller sizes for males coincide with the upper size classes of the females. About 130 millimeters and larger are mature males while 130 mm to about 85 mm are mature females. So if you exclude the lower size classes of mature males you would automatically exclude females.

D. ARMSTRONG: This fishery has been under way for three years in Fort Lauderdale?

D. NIELSEN: Yes, but in a very dormant state. We primarily earn our living with fish traps and lobster here. The vessels we have are too small for large-scale crabbing. Howard Rau already has a larger vessel and is gearing up for the golden crab, as well as fish trapping and lobster fishing. I am working on a new vessel now. It has been a long slow process gearing up for these fisheries. We have done the ground work, we have used the technique of grappling these traps and catching the crabs, and we have that behind us. We haven't really supplied crabs to market consistently, and the market looks good to me. We've shipped crabs all over the world; we've shipped crabs all over the country and it's been widely accepted, only we couldn't meet the demand. We have been pretty well stable and now that we're about to move out and start greater harvesting, we want to go to the federal councils and get some regulations in place before this industry takes off.

D. ARMSTRONG: Presently are there any state regulations at all?

D. NIELSON: Not to my knowledge. I don't know of any.

D. ARMSTRONG: Will the State automatically come in immediately or at some point when they sense the industry is expanding?

D. NIELSEN: When you fish federal waters the State of Florida has no jurisdiction. We work very closely with the federal councils. We are regulated with fish traps and lobster gear in federal waters, and we have a good relationship with the federal councils. I don't see any problem with going before them as fishermen and proposing these regulations, to get them in place so we can protect this resource and have it for a good many years down the road.

R. ERDMAN: The only thing that the State does presently is to code the species as part of the State's statistical analysis. The State presently records only gross pounds landed.

N. BLAKE: The State of Florida has been reluctant and will continue to be reluctant to either do any research or to participate in any regulations that involve a fishery in federal waters even through the catch from that area is probably totally landed in state waters. They just will not participate in any of the shell fisheries that involve federal waters.

D. ARMSTRONG: And that simply means beyond three mile limits?

N. BLAKE: Well, no, it varies (nine miles in the Gulf).

D. ARMSTRONG: It's surprising in a sense because most landings of dungeness crabs, for instance, are beyond three mile limits but states have jurisdiction. In fact, the federal government has abdicated authority in those instances and only retains it in partnership with, say, a state like Alaska in the case of Snow crab and King crab fisheries. It surprises me the State could never come to have their specific regulations and standards and enforce them.

F. LAWLER: This fishery was started after the Magnuson Act went into effect. The fisheries on the west coast were going long before that. I think that's one of the reasons why the western states retain jurisdiction and Florida doesn't in this particular fishery.

D. ARMSTRONG: Also in some cases with relatively little fisheries value, the federal government cannot afford commitment of funds to persistent monitoring and management of them, so it falls to the states to do so.

H. RAU: I think it's safe to say that we would oppose the golden crab being put under the jurisdiction of the state of Florida.

G. ULRICH: If you fish an area for a while do you notice a decline in the catch?

D. NIELSEN: We were very limited by the size of the vessel, 36 foot, and the hydraulics. The depth of the water limited us to working a certain area and we stayed in that area at that same depth. We yielded about

100 pounds per trap per week for two years. We weren't able to expand out deeper or move around like we normally would because of the vessel, so I can't give you a real answer to that question.

R. NIELSON: I wanted to add just a couple of things. To achieve that 100 pound average for over a year and a half, we were fishing from approximately 118 fathom to 125 fathom in the same basic area. There has been some talk about how much pressure the resource can stand, and either those crabs were six feet deep when we started or they were being drawn from a wider area than originally thought. These crabs could be moving miles to get to these traps because it's amazing the amount of crabs we took out of this one area. We would still be doing that today except another fisherman came and set more traps in the area right outside of where we were fishing, and since then I have moved to a different area. The catch has not been up to a 100 pound average, but there are days that we average 50, 60 pounds of crab which is acceptable to us.

Let's talk a little bit about marketing. When we first started marketing this crab we ran into all kinds of problems. Originally, we sold the crab whole. People took it home and boiled it for an hour and a half trying to get it to turn red, then would come back and complain. We got into the retail market where we sold fish and crabs. We talked with the owner to basically inform the people and had some brochures made up that explained how to cook the crab. We found that even when people cooked golden crab for 18 to 20 minutes and then pulled the carapace off, they had a mess on the top of their table and that turned people off. So we decided as a marketing gimmick to clean them free which would help the retail markets. When people buy these crabs in a retail market they pay for the whole crab, and the retail market splits it and cleans it so the people take home only what they eat. It's much easier for them, no muss no fuss.

Once people try this, they call the fish market every day. We can't even catch enough crabs to keep one retail market steadily in crabs. I brought in 500 pounds of crabs on Wednesday and they are probably gone this afternoon.

I think down the road that you're going to find its the live market that is going to last. We've had large boats from Alaska and Massachusetts come down and try to process and freeze the crabs on the boat, and they have all gone out of business. I think you'll see the only market that's going to last is for live crab. You can pack these crabs in styrofoam boxes, put a couple of ice packs on the bottom and couple on top, and ship them to Massachusetts, or to Spain. The crabs will get there with approximately a ten percent mortality rate, which is pretty decent. A lot of people won't eat a blue crab if it's dead. When a golden crab is dead you can butcher it and cook it, and it's perfectly fine. As for the shelf life, once a cluster is cooked, you can keep that crab in your refrigerator for five or six days and it's still perfectly good. It holds the flavor and doesn't spoil. You have to cook the cluster. If you don't cook the cluster, black spot occurs in a matter of hours, so once a crab is cleaned it has to be cooked.

One of the things I'm interested in, and that would interest you people, are the small crabs. From the reports we had yesterday no one knows where the juvenile golden crabs are. I would like to find that out. Just where do they go, are they way down deep and then migrate in shore as they get sexually mature?

I would like to say once again that if you are down in the Fort Lauderdale area and you would like to go out and see how we fish for crab, you are more than welcome to come out for a day. If you are planning studies, our boat is always open to anyone who wants to do the work to help the resource. I thank you for inviting us.

D. ARMSTRONG: I'm curious, what is the crab worth per pound either off the vessel or retail?

R. NIELSON: We get a dollar a pound off the boat, retail is anywhere from $1.49 to $1.69 a pound. We started out trying to get $1.50 off the boat, and they were selling it for $3.59 a pound retail. We had to cut way back. We were down to 75 cents, and the retail markets were selling them for 99 cents just to get it established. Once we got it established we raised the price up a little bit so we could make a decent buck at it.

A. HINES: That's for whole crabs?

R. NIELSON: Yes, that's the whole crab.

N. BLAKE: You've got to remember they are fishing some six to ten miles offshore, you couldn't sell it on the west coast of Florida at a dollar a pound because the fishery is 100 to 150 miles offshore and you need a much bigger boat. Your investment would be much greater almost any place besides the Fort Lauderdale vicinity.

R. NIELSON: We have it easy in some respects, by fishing only five to ten miles off the coast. But it's not the easiest thing in the world to fish in a two to four knot current, especially using the grapple to hook the traps.

R. MILLER: How large an area did you fish over the two years before you moved your gear, how many square miles of bottom?

R. NIELSON: I would say approximately six square miles.

R. MILLER: How many pounds did you take out of that area?

R. NIELSEN: I don't have an exact figure, but roughly an average of a thousand pounds per week for over a year and a half. Seventy-five thousand pounds would be a rough figure.

D. ARMSTRONG: Have you lost gear using the method of grappling?

R. NIELSON: No. When we first started we would go out there and grapple for six hours and not even touch a trap. Once you get used to it and get the technique down, you let the current work with you instead of against you. I've lost one trap to the bottom in three years.

D. ARMSTRONG: Do you have any feeling whether the traps would continue to fish through extended periods of time without bait, that is just by virtue of habitat itself?

R. NIELSON: We have stainless steel gates that hang down to allow the crab in but are not supposed to allow the crab out. Once the bait goes, these crabs will find their way out of the trap. Similar to the fish traps, we use what's called a wire tie which is a small diameter wire that construction companies use to tie rebar together. We use it on the golden crab traps in case the traps are lost, so eventually the door will open.

G. HINSCH: Do you get any of the giant isopods when you fish for golden crabs?

R. NIELSEN: No.

G. HINSCH: That's a by-catch in the Gulf of Mexico fishery.

R. NIELSON: I've seen them from the Keys, but I've never caught one. One fisherman in the area has caught one.

G. HINSCH: They are quite common out here.

R. NIELSON: We don't see them, probably because we're not fishing deep enough. I imagine if we get out farther we'll run into them.

F. LAWLOR: What other kinds of by-catch do you get?

R. NIELSON: Very little, we get a Cancer crab once in a while. On a big day you might have 20 pounds. There is a spider crab, Rochinia, that seems to be more on the upper depth limits where we fish. If the gear is moved to the inside limit of the golden crabs you'll get five to six of them in each trap. I caught maybe ten fish in three years, blackbellied rose fish and a Snowy grouper. Howard Rau caught a Spiny dog fish, another guy caught a Goose fish, and we caught one American lobster.

G. HINSCH: Did you ever find any shovel-nose lobsters?

R. NIELSON: No. We do catch them shallower in our fish traps, but we don't catch any out there.

W. LINDBERG: Sean or Howard, do you have any words of wisdom you care to pass along to us?

S. INGHAM: My name is Sean Ingham. I'm a commercial fisherman from Bermuda, and I would like to thank all of those who have been instrumental in inviting me to this workshop. I have learned quite a bit and it's generated quite of bit of food for thought regarding the future in Bermuda. I'm going to go back with this information, sit down with the authorities and see if we can come up with some answers and try to develop a fishery for golden crab in Bermuda.

At the moment I'm the only person working it in a very small way with just a few pots. I had to go south to Belize to set up a fishing operation, and while there we attempted to find golden crab but didn't. Instead we got a lot of Bathynomus isopods. We got our fishing operation going there and came back to Bermuda where I've only been back into fishing for about a year. This year I'm optimistic. I'm getting back into it, and we're in the infancy stage. No real markets are established in Bermuda, so I have to both catch and develop markets. Only a few restaurants use golden crab.

When we started back in 1984 with golden crab; we sold the crab live at $2.50 a pound, and the restaurants were able to make money. I think now that we can still maintain those prices even with inflation. As I said, we have to do everything ourselves right from square one. We have had promises from the Bermuda government to help us. Any questions?

N. BLAKE: What kind of catch rates do you experience?

S. INGHAM: Well, fishermen loathe change, particularly in Bermuda. They did not want to venture into new types of traps which you are familiar with, even with the documentation I got from Ray Manning and Warren Rathjen. We needed a trap that could be utilized both for fish and crabs, depending on the time of year, the circumstances, and markets. I was working an eight foot by eight foot, four-foot-six high trap, which was set around July 1st in 1984. We went back on July 4th, and we didn't know what we were going to catch, since none of the authorities could tell us what was out there. They told me I was wasting my time, there was nothing out there, and to forget about it. So these crabs came up on July 4th and jokingly we called it the Independence crab, because it was going to make all the fishermen independent.

Later on as we moved these traps into the areas between the banks and Bermuda's edge where the strong currents were, we had one trap that came up virtually packed, and we couldn't get it aboard the boat. Eventually, it just gradually broke up against the side of the boat. So then we started fishing smaller traps that we could manage better, and we found as we went down in size, the trap caught less. But we were averaging 30 pounds a trap, sometimes less, sometimes more. With smaller traps the crabs either got out or we didn't have much success. The shallowest depth we found the crab was in 420 fathoms, nothing shallower than that. We have tried up and down the slope and haven't found any.

E. WENNER: Have you found the sex ratios to be roughly equivalent off Bermuda? I know that Brian Luckhurst reported that, and I was wondering from your experiences whether you found a fairly equal number of males and females?

S. INGHAM: Most of that information Brian Luckhurst has. I have had enough to try and catch it and market it. We used to chill the catch down to about 26, 27 degrees Fahrenheit, and this narcotized the crabs, and stopped them from attacking each other. When we got in, that catch was weighed, and Loran fixes were available for Brian's information. He would have all that information.

D. NIELSON: What depth of water were you fishing?

S. INGHAM: 420 fathoms. We found the species of crab at that depth was the biggest. As we went deeper the crabs got smaller, and then a smaller species started. We went out as far as 1,900 fathoms. This year we're intending to go down to 2,800 fathoms relatively close to Bermuda on a one shot deal, because I'm now in the financial position to spend all my time researching. I was relatively close to shore working in a mile of water.

D. NIELSON: What size are these crabs, the largest male, four pounds, three pounds, can you give me a per crab weight?

S. INGHAM: We caught some very big crabs in the five to six pound range, and on one crab the carapace was about 20 inches across. Mind you, the funnels in the traps are large. I've seen the Nielson trap, and your funnels are not that big. I would say if you tried bigger funnels in a larger trap you may find a larger crab. With what you've done now, you're limited in the size crab you can catch, and that's not necessarily the biggest. The biggest one was weighed by Luckhurst at 16 pounds one ounce.

R. WALLER: Are we dealing with the same crab here?

S. INGHAM: There has been very little help from the government to determine that.

F. LAWLOR: Were you taking both males and females?

S. INGHAM: That's true. At the present moment we are still taking both sexes. No laws govern the crab in Bermuda. Similar to the FDA laws that you have in the United States, we will follow your example. Whatever laws you enact up here, we'll probably follow suit down there.

When the crabs came up, both the scientists and fishermen looked on it as a waste of time to throw the females and smaller crabs back because they were going to die. We didn't realize what a strong constitution these crabs have. We have found that out from the seminar here. Where machinery and refrigeration has failed, crabs have been held up to 50, 60 degrees and live. I think they have a chance if we can work out what size crab we're going to release. The mesh size we were working with was two-inch by two-inch mesh.

F. LAWLOR: Is that the size you use on the fish traps?

S. INGHAM: Same size on the fish traps. We are a heavily regulated fishing industry in Bermuda. Back four or five years ago, I had 100 legal traps. Prior to that it was 400, and they have cut me from 100 back to 50, and from 50 I've been cut back now to 34. This year we're being cut back to 26.

I have tried to find an alternative way of fishing in Bermuda for the fishermen, and have tried to get away from more traditional types of fishing because of complaints about overfishing, the targeting of small herbivores for filet, and the limited space and platform that we have to work on. I'm trying to find an alternative that the fishermen can get into and continue, but we need to regulate that right from the beginning rather than at the end and try to bring it back, which always has been a big problem.

R. MILLER: Conventional wisdom is that animals that deep are probably quite old and quite slow growing, so your fishing operation could be viewed as a mining operation rather than a sustained yield. Some other people have more experience with these deep water habitats, but I think that would be a safe generalization. You'll fish an area out once and the next time it will be your children who will fish it again. We won't have a sustained fishery at great depths for any commercial species.

M. BLAKE: It hasn't been brought up yet, but if we're talking management, sometime along the line in this fishery we should be talking limited entry, whether it be in Bermuda, in the States, or wherever. I don't know how the Nielson's feel about that but if 500 people see a resource out there, especially in a deep water species where it could be fished out quickly, limited entry may be the only answer.

S. INGHAM: As for limited entry, in Bermuda the fishermen have worked single traps. We attempted to use traps on strings and it didn't work out too well. We set traps about 500 feet apart but they tended to get snared up in the rocks. Now we have the knowledge, we've seen enough films and fishermen working.

Just a point of interest, doors on our traps, as part of the law in Bermuda, are tied with biodegradable rope by law. We also found that a conventional fish trap that's set in five or six fathoms, will last approximately three years. You go out to 30 fathoms, you get about two years from a trap. You take that trap down off the edge and go out for crab and you get about three months because the wire starts to erode very quickly, either from electrolysis or what, I don't know. The sisal rope in shallower waters is discolored after about six weeks. In 500 fathoms, that size of rope looks perfect six weeks later, but two weeks later that rope is perfect to look at, looks brand new, but falls apart. It's very interesting and I don't know why it happens.

We were catching most of the crab up into the north and northwest, and the bait in the trap was in excellent condition sometimes a week after. On the southern side of Bermuda, we found that the bait after just one day looked like it had been cooked. I thought it was being attacked by some type of bacteria but some scientists suggested it could have been hot vents.

W. LINDBERG: Why don't we shift gears and turn the floor over to our rapporteurs to try to integrate the biology from yesterday with some of the fisheries comments from this morning.

....

R. SMITH: For Chaceon maritae, I would argue that it doesn't have a terminal molt. I propose that molt plus one other, in other words two mature molts. I think you know there are several reasons for that. For starters I have kept mature animals in tanks, and they have molted to soft shell, I am quite convinced that they are not terminal molters. Then related to the up and down movement pattern, I've done a lot of tagging, and I've got to look at it from a seasonal point of view. It tends to suggest a seasonal movement up and down, but by size. In other words, as soon as they got a little bit bigger they tended to repeat the tag returns from a shallower depth interval; as they were getting larger they moved up shelf.

A. HINES: Would that be just by default? If little ones are only found deeper, as they grow they disperse from that zone, and then you would tend to get them at shallower depths, or do you think it's really a directional movement?

R. SMITH: I'm not quite sure, but what I would say is that generally the slope is of a distance that they could easily move five, ten miles up slope and get to whatever depth they would like, so it seems that they could easily move that distance if they wanted to. It seems that shallow is more suitable to them.

R. WALLER: I think they would be moving up slope in reaction to food. More food would be up slope than down slope, and the larger animals that require more to eat would move to an area where they might feed better.

R. SMITH: Could be.

G. HINSCH: Roy, you have two mature stages for females?

R. SMITH: Yes.

G. HINSCH: You don't think that the second one molts again, and that isn't a terminal molt in that instance? You think they molt to that second mature stage and then just die?

R. SMITH: The period between these first two mature stages is so extended, probably about four years or so. Maybe they never get the chance to molt again because the third mature stage might be so extended that they never even reach it, might possibly get taken by predators before then.

Another thing that also makes me think that they have two mature stages is that portunids have a series of two mature stages. As Ray Manning was saying, the Geryonids are so closely related to the portunids, that they possibly have the same pattern.

G. HINSCH: But if you assume that any animal within a single instar would vary, they would not all be the same. Wouldn't you expect to see some sort of a double bell curve in the sizes?

R. SMITH: No, you don't.

G. HINSCH: With Chaceon several people have shown that the maximum size of females is approximately 13 and a half centimeters but they hardly ever find them beyond that.

R. ERDMAN: We have recorded ovigerous females as wide as 156 millimeters.

G. HINSCH: Very few of them.

R. ERDMAN: But I have never seen any bi-modal suggestion in my data.

G. HINSCH: That's what I'm saying. If you were to have two different stages wouldn't you have a bi-modal situation, with one instar having the largest frequency at one point and then the next instar having again a large number of individuals?

R. SMITH: I don't think you would see that because you took data at the end of it's life history and by that stage there are all sorts of different growth patterns.

G. HINSCH: But in Chaceon, females release their eggs, their embryos, and internally they have fully developed ovaries. If you consider the energy necessary for ovarian development it would seem very unlikely that large numbers of females are going to undergo vitellogenesis and release their larvae, with vitellogenesis occurring at the same time as larval development and then not continue on to have another brood from those eggs which they contain within them.

W. VAN HEUKELEM: I don't think you would see a bi-modal distribution as Tuck Hines was talking about, possibly because of large growth increments. The only juvenile we had that was any size was 82 centimeters and it molted to 91. That's only an eleven percent increase at the molt for that size. If you have much variation at all it's going to wipe out a bi-modal distribution. We found with our juveniles that they started out with about a 43 percent increase of stage one to stage two, and by the time they were going from crab six to crab seven it was down to about 14 percent. It looks like as size increases the increment percentage decreases.

A. HINES: You could have a declining molt increment with increasing size so that the juveniles would have a fairly high molt increment and the larger adults would have decreasing molt increments.

W. VAN HEUKELEM: That's what our data show.

A. HINES: That's common in xanthid and grapsid species.

P. HAEFNER: To follow up on one of the things that Tuck Hines was saying about taking careful measurements and observations, I haven't heard anything expressed here about observations on parasites of these crabs. I don't know the growth rate, for example of the octolasmid barnacle, but if you see a crab that's loaded with large octolasmid barnacles, you get some sense as to how long ago it has been since that individual has molted. You should see the same thing with parasites in the gill chambers. It takes a little more effort and a little bit more time to look for these things, but I think it's worthwhile in the long run.

A. HINES: The most obvious commensal with these species are the stalked barnacles that occur on the carapace.

R. ERDMAN: That not Octolasmis, it's a poecilasmid. There isn't enough known about the biology of that species to know how fast it's growing.

P. HAEFNER: We need to get some commensal biologists involved here too.

G. HINSCH: With one specimen there was a large polychaete worm about six inches long. I don't have the name with me but I can get it. This was found in the gill chambers of the red crab, we never found it in Chaceon fenneri, but they were quite common.

A. HINES: I think that you can get some information about that, but it's more qualitative information, and I would be cautious because it's difficult to make strong inferences from that. It helps support more direct information from the crabs and their molt stage, so I think it's worthwhile.

R. ERDMAN: Regarding both commensals that we just discussed, the barnacles we've collected from both Chaceon fenneri and quinquedens have been sent to Dr. Williams in Wales, thanks to Tuck. That group appears to be a taxonomic nightmare. And regarding the gill worms, we have collected extensive numbers of polychaetes from Chaceon fenneri from both the east coast and the west coast. They seemed to be fairly common. Tom Perkins from Florida DNR has identified them.

E. WENNER: We also found this particular polychaete in Chaceon fenneri in our collections.

D. ARMSTRONG: I have a question both for the fishermen and probably Bob Elner and it has to do with your desire to predict consequences of certain actions, and this relative to the ecological role of the animal in the community. To date the fishery has been very gentle, in fact not nearly big enough to have some sort of impact, probably on the standing stock of big animals at the top of the size range. It is in fact the mining point of view that you suggested, Bob Miller, which is to say it's right now like some of the virgin Snow crab populations, old animals tending to inhibit growth of younger age classes. Once removed, the big animals will obviously be a rare commodity but also will evoke certain kinds of reactions in the population as a whole. A lot more may grow, but to smaller sizes. How does the Canadian government approach exploitation of that kind of a fishery which is predicted to be slow in recovering, and how would fishermen want to handle it in this particular case? We heard the suggestion of very limited entry as one type of regulation, but I guess you might need to be prepared for the possibility that your fishery comes to an end over a fairly short time and takes a long time to recover.

S. INGHAM: I would like to say that if any study is going to be done in Chaceon, Bermuda would be an ideal place to do it because of the quick incline of the slope. At 420 fathom the larger species disappeared and at about 500 fathom another species took over. You are in close proximity to land and we have a day-time fishery, no one really fishes at night.

A. HINES: What species is that?

S. INGHAM: Chaceon Fenneri.

A. HINES: Do you see C. quinquedens?

S. INGHAM: Yes. There are several species there but they seem to be governed by depth. The largest of those species are at the shallower depths and the smaller ones deeper. You're within a very short distance of these depths, whereas along the continental United States one has to go many miles before depth changes. Also the funnels of the traps may be a very good device to protect the larger species. By restricting the size of the funnel, you leave the larger species for reproduction. I don't know if anyone has got any comments on that.

A. HINES: So you're suggesting then that there be both an upper and a lower size limit on the catch.

S. INGHAM: Once we know the maximum size of the species that is being targeted, I think something could be done along those lines similar to what has occurred in Maine with lobsters. I would like to hear more comments on that because I don't know what effect that will have.

P. HAEFNER: One thing to add about the American lobster. We have the classic case along the east coast, off the coast of Virginia when they discovered an offshore lobster population there. The very large 15, 20 pound lobsters were fished out very quickly down to five and three pounds. I lost track of the status of that but perhaps either Bob Miller or Bob Elner can relate to that in New England and off Canada. You can very quickly deplete the big individuals, and if Chaceon is indeed a very slow growing species, with intensive fishing efforts you probably would see a reduction of that upper mode. Of course, I don't know if Roy Smith has experienced that either.

R. ELNER: I think it all points to the real importance of monitoring this fishery as it takes off. You are looking at the number of soft shell crabs in the fishery every year and looking for other signs of recruitment. To get back to Dave Armstrong's question, until we know that recruitment we must proceed cautiously. If it is a mining operation, there are a number of management strategies you can use. You can use measures whereby you only fish that species every ten years or every five years. Alternatively you enclose areas and fish one area for two years and then close it for five years. Or you could make sure your exploitation rate is very low so you can let very few fishermen in the fishery. There are a number of management strategies, but it all depends on the response of the stock harvested in terms of recruitment.

W. LINDBERG: Getting back to one of the comments that Dave Armstrong made about the Alaskan fisheries, that recruitment events may be occasional although reproduction may be regular or annual. Successful recruitment events don't necessarily follow from that. In a comparative sense being long lived, with late maturity and a tremendous investment in reproductive effort compared to other crabs, could it be that we are having trouble finding juvenile size classes because this is only an occasional event? If an animal is living for 30 years and reproducing annually over a good portion of that time, could it be that successful recruitment from any given individuals's brood is only happening a small percentage of that time?

A. HINES: That's a distinct possibility. I think that we really don't know enough to answer that question for sure about any of the species of Chaceon, but we have similar cases in other species of crabs to show that's a possibility. The Snow crab situation and also King crab that Dave Armstrong mentioned seemed to indicate that's a possibility. In the case of Snow crab, changes in size structure of the population are concomitant with fishing pressure, and seems to result in differences in the mating biology and relative contribution of different sizes to the reproductive output and reproductive success of the population. That can vary geographically among fishing sites through the range of the species. It is something to be concerned with.

That kind of information is needed on Chaceon, but it's not something you can answer quickly; there is no simple test for it.

R. NIELSON: I fished New England lobsters in Massachusetts for about 20 years. The question here is the large animals and what's going to happen to them. It's been my experience that with any new resource in the marine field, you're working on the large adults and those are taken right off the top. Then, it comes down to a level where you get an annual yield, so I really don't see a problem with that. The larger animals are taken right off the top of the resource. That occurred on the offshore lobster fisheries up in New England. The inshore lobster fisheries which I participated in ended up so that we were taking a certain size lobster down to a level, and we were throwing back the smaller ones that were next year's stock. We were then harvesting every year, and it stayed at that level for 20 years. I've been out of that fishery for over 18 years now and it's still at that level, so I don't really see a problem of taking heavy, larger animals off the top of a resource.

Secondly, the state of Maine is the only state in New England that has the large carapace measurement to protect the larger male and female lobster. I don't see any purpose of it. I don't see where it's helped them, but it probably hasn't hurt them.

A. HINES: The real concern in most fisheries management strategies is to be sure that the size restrictions exceed the size and age at first reproduction, and that it not be just physiological reproduction but that they're functionally able to reproduce. For example, in the Dungeness crab fishery and in most crabs, males must be larger than females in order to mate. So while a small male may be physiologically mature and capable of reproducing, in fact, they are not contributing very much to reproductive output of the population. You must have that minimum size females, for example, related to the functional reproductive biology, not just the age at which they become mature. We need to know a little bit more about that in Chaceon. We don't know enough yet. I have seen males in copulating pairs and the few data we have show males are quite a bit bigger than the females, not just equal to the largest size of the females.

D. ARMSTRONG: I would tend to agree that an upper size limit doesn't seem wise or necessary in this case. And the trick is whether or not there will be sufficient size differential between your economically viable minimum and that of a crab which is also bred. The fact that so many people report low percent ovigery, but at times that it's high, is somewhat troublesome. In most other crab fisheries that are surveyed, those females of theoretical mature size are almost always 100 percent ovigerous in season. Yet for these animals a lot of times tiny fractions are carrying eggs. It may just be a quirk of continuous reproduction at depth, as has been suggested, but it also could be evidence that they don't all reproduce annually.

I was going to ask Bob Whitlatch, that if these animals are severely food limited and, considering the size frequencies for males, the fishery crops the population to 140 millimeters, and that provokes some sort of numerical response in terms of more smaller crabs, can you anticipate any effect that might have on the overall community?

R. WHITLATCH: To my knowledge I can think of no good example. A lot of times you don't see immediate responses to predict this in terms of typical fisheries.

D. ARMSTRONG: They have got to be either worse off, better off, or no different in terms of the overall food supply for more smaller animals if they have this cap of larger animals removed.

R. WHITLATCH: One would predict that there should be a response of the food resource availability as the predators decrease, although there are other factors involved. Fishes might replace the crabs and have a similar sort of cropping behavior. We don't know a lot about the feeding ecologies of these deep water organisms. By the way, an unpublished Ph.D thesis by Jim Farlow of Yale University deals with gut contents of trawl surveys. Generally most of these large forms are really opportunistic feeders and it's felt that they crop their food resources very nonselectively. So the presumption here is that if you decrease one species you might increase another species.

W. VAN HEUKELEM: I would just like to reiterate what's been said several times in terms of learning more about the importance of juveniles, where they are and what their movements are. I think we have pretty extensive trawl surveys on Chaceon and have only gotten very few juveniles and those were at great depths compared to the adult population. I was interested in Roy's comment yesterday, that they found a lot in fish guts so they knew that they were in shallower water; it that right?

R. SMITH: That's right.

W. VAN HEUKELEM: So this dissertation might be very interesting to look at.

R. WHITLATCH: I would also reiterate several comments people have made about the importance of integrating information that is required to understand the resource for fisheries and the importance of the genus in the slope environment. We have a somewhat unique situation here in terms of research initiatives and funding agencies for this sort of research. Many of the states are not going to be interested in supporting research activities that occur in federal waters. Research could be motivated by two issues, the basic biology of the organism and the role it plays in upper slope communities. At the same time, gain the appropriate information that people have pointed out concerning the crab's potential as a fishery resource.

A. HINES: I would like to second that. From Ray Manning's discussion of the increasingly apparent diversity and world wide distribution of this group, what we learn about the biology of Chaceon species in the U.S. and off the African coast is likely to have world-wide implications for that depth zone in the ocean. From a basic research point of view as well as fisheries management, there are important issues. We're learning a lot about that depth zone, and we're bringing new technological advances to bear on those research issues that we haven't been able to approach in the past. In my view, it's somewhat analogous to the rocky intertidal ecologist suddenly donning scuba gear and finding out there is a whole lot going on below the low tide mark. There is indeed a lot going on in the typical fishing zones that have been sampled in the past.

Secondly, there are other aspects of the biology from a community point of view, on trophic interactions, that we haven't raised here. We've talked a lot about this depth zone that seems to be consistent and distinct when two or more species of Chaceon overlap, and that there is a vertical segregation with C. quinquedens, for example, always found deeper than C. fenneri. Well, why is that, what maintains that? It is simply some intrinsic depth preference of temperature preference or are there biological interactions between fenneri and quinquedens that you might expect to observe that would be competitive, either exploitative or interference competition?

We haven't talked about competition among individuals. If food resources and access to mates are really important, that would suggest why this species has long distance sensory abilities, and also potentially could suggest a reason for the common occurrence of black scars on the crabs that might be due to aggressive interactions, or could be just due to crabs banging into things on the bottom. We see that both on C. fenneri and C. quinquedens and I suppose on other Chaceon species.

And finally, we raise the issue about what are some of the predators on these crabs. We talk about fish preying on the juveniles, but we don't know how common that is or how important that is to the fishery resources on that slope. It would be worthwhile, if you fishermen catch some fish in your traps or in your trawls, to look at the stomach contents of those fishes and determine whether they have little crabs in their stomachs.

W. LINDBERG: On the questions of species interactions, with our broad scale sampling in the Gulf, if it was species interaction setting an upper limit for red crabs, then you would expect an ecological release in the absence of C. fenneri. We don't see this in the northern Gulf where the bottom types are appropriate, with predominant by mud-silt bottom at shallower depths. There are no C. fenneri there. If species interaction set the range, then you would expect C. quinquedens to move up, and they don't.

R. WHITLATCH: In New England we don't have C. fenneri, but it's been suggested that Cancer irroratus is out competing Chaceon quinquedens in the shallower waters. So there may be another species, maybe not a Chaceon, that is fulfilling the role that C. fenneri is playing.

W. LINDBERG: If it was filling the role of C. fenneri you might expect it would be sampled in the same fashion as C. fenneri, and we didn't have that. The intermediate and shallowest depths in our sample weren't producing some replacement for C. fenneri. The C. quinquedens were simply not moving up, which suggests something else is limiting them.

C. TRIGG: We don't see aggressive behavior when we hold the species together in overcrowded conditions.

W. LINDBERG: There may be not be cannibalism, but with trap observations, we do see clear aggressive behavior as they first approach the trap. There are cheliped displays, there is contact interaction, there is a fleeing of the smaller individual, things that are characteristic of all the other crabs I've seen. If there are low frequencies of molting and a small proportion of the females are receptive at any given time, there could be some fairly intensive competition among the males for mates. Given that they are incopulo for such a long period of time, rather intensive sexual competition is suggested.

R. ERDMAN: To return to bathymetric distribution, we have completed oxygen consumption measurements over temperature ranges on Chaceon quinquedens and Chaceon fenneri. The experiments were this fall, and I haven't finished the analysis, but we did measure both species and both sexes over time in a respiration chamber. From visual observations, there seemed to be a slight sluggishness at warmer temperatures with C. quinquedens. They just don't do as well. They survive but are inactive and don't feed. Data that are published, whether from gray literature or not, suggests an upper temperature limit. Yet, the species has been recorded from temperatures as high as 12 degrees Celsius, but some of the gray literature reports that above nine or ten degrees the species begins to show potential physiological disturbances of physiological discomfort.

R. WALLER: Depth distribution is really interesting. Sean said he didn't collect C. fenneri at depths above 420 fathoms, and yet in the Gulf we get them at 200 fathoms which is our best sampling range.

R. ERDMAN: On the east coast when we first started to work with Dick Nielsen, we were fishing about 120 fathoms. We set traps in the Gulf at 120 fms and got one crab. On the east coast of Florida the Gulf Stream spills onto the shelf along the Fort Lauderdale area. It would be interesting to see what the temperature is like in the Bermuda area. Obviously finding out the physical conditions are very important.

R. NIELSON: When I was catching more crabs than I had markets for I decided to take a couple of trawls of traps and see how far in I could catch the golden crabs. At about 600 feet I only caught a few, and inside of 600 feet there weren't any. Beyond the hundred fathom curve, you didn't really get into crab around 118 fathoms. At that depth there were a few but not enough to be commercially viable.

R. MILLER: Two rather extensive comments. First, distribution and abundance is what seems important for both ecological and fisheries applications. As biologists we're not very experienced in giving density estimates of large deep water animals. I think the funding agencies should be patient with applications, that simply refine and develop measuring real density, and absolute density of these animals in deep water. It's not glamorous perhaps but it is necessary.

A. HINES: Certainly the videos on the submersibles are a very good way, but very expensive way to do that.

R. MILLER: Secondly, regarding a management plan, if I were to make one, initially I would do it exclusively from economic considerations. I would set a minimum size based on what you could sell. Don't waste it, only catch what you can sell, independent of considerations of reproductive size. I would expect that, at least now, there are a lot of refuges inaccessible to fishing either because of depth or because of low density of the prey animal. I think one could fish until you get down to a certain minimum. If the industry is uncomfortable with that, set a tentative quota, say three million pounds for southeast Florida. If it takes one year to get there or five years to get there it doesn't matter. When you get to two million pounds close the fishery for five years and open it again and start over. But it's going to be, I'm almost certain, a mining operation or very close to that. The American lobster is not, unfortunately, a good parallel because it's a shallow water, fast growing species and these animals are not, I'm sure. You're going to fish them once and leave them for maybe another generation of fishermen.

R. WHITLATCH: No one has said anything about black spot disease, is that a concern? In New England it's of great concern and it's been suggested that red crabs might be a good model to use to look at the incidence of black spot disease.

E. WENNER: What he is talking about is not melanosis but the presence of chitinolytic lesions. We found 99 percent of the individuals that we sampled had incidence of chitinolytic bacteria. In some cases it was very extensive. It is certainly of interest that in blue crab populations that is also beginning to show up in North Carolina. It's also extending to South Carolina and is being picked up in Chesapeake Bay now where it is being related to pollution. I think we definitely need to know more about why there is such a high incidence of chitinolytic bacteria in Chaceon fenneri and Chaceon quinquedens in the deep sea.

R. WHITLATCH: It's one more motivation for studying the animal. I'm thinking if we can't interest agencies that are interested in the organism or the fisheries resource we might interest agencies that might like to use it as a monitor for pollution on the upper slope. We can broaden our base here.

A. HINES: Any other comments?

D. ARMSTRONG: Just a point of interest, I'm always curious where people get their crustacean funding. You've been on a little bit of a roll in this part of the world, what do you anticipate the source and likelihood and level of funding will be? Is it all going to be federal government or will your Sea Grant and local states continue this for five years?

W. LINDBERG: Well, the prognosis isn't all that great. I would say we have been riding the wave of fisheries development in the southeast and now we have a handle on this. It doesn't have that appearance of being another King crab or Snow crab, although it can be a viable localized or regional fishery. Motivation from Sea Grant, National Marine Fisheries Service, and the fisheries development view has probably run its course.

D. ARMSTRONG: That gets back to Bob Whitlatch's comment of hooking the wagon to other ecological types of studies and agencies to fund it.

E. WENNER: I have that distinct impression too that we were able to acquire a fair amount of funding through the region. This type of research takes a lot of funding. Just from my own experience, I received funding from five different agencies, and put it all together into one package which required a great deal of effort. But it required a great deal of money to be able to do the work. What I'm sensing now is that with golden crab being the only topic of directed research efforts, I don't think we're going to be as successful in getting that funding. These species are going to have to be looked at in a more ecological or community role, as opposed to golden crab being the sole focus of the research.

W. LINDBERG: That's part of the agenda in bringing so many different people from different regions and different viewpoints together. We have the opportunity to forge interdisciplinary or multi-investigator approaches to the broader scale ecological questions; that's in all of our best interests, especially when viewed on the comparative basis that Ray Manning has given us, and considered in the broader context of other crustacean fisheries.

A. HULBERT: Certainly our research center is very interested in this problem. A large part of the reason for participating in this workshop is to get a multi-disciplinary group like this together. The center in the past, as Betty and Bill know, has been effective in providing the equipment and utilizing that as a seed along with other kinds of funding like Sea Grant and state agencies. Certainly from our point of view, the funding that we're looking at now, and the research agenda, is for big scale projects. The kinds of things that are fundable are Gulf of Mexico ecosystems versus South Atlantic ecosystems, and what functions are involved, and the integration of physical oceanography with larval recruitment processes. Those are very important things we can do. We have very good reason to reach out to marine geologists and hydrologists, oceanographers, in terms of funding. Put your interests in context of a bigger plan, a multi-interdisciplinary study, and use it as a seed to get together and go forward.

W. LINDBERG: That perhaps is the best wrap up to have. Something to go home with, a challenge to work with. I would like to thank all of you for taking the time out of your schedules to come here and enjoy the Florida sunshine. We formally stand adjourned.

SUMMARY OF RESEARCH NEEDS AND OPPORTUNITIES

Kelly et al. proposed a model for C. quinquedens larval transport in surface waters which was supported inferentially here by R. Smith for C. maritae and Lindberg et al. for C. fenneri. As noted by W. Van Heukelem, rapid larval development rates at warmer surface water temperatures should favor the restricted geographic distributions of geryonid species reported by R. Manning. Is vertical larval migration and surface water transport the rule among geryonid crabs? If so, what are the general implications for recruitment processes and life history strategies of these crabs and associated fauna.

Juvenile geryonid crabs rarely appear in samples, and then mostly from deeper collections. This pattern led previous authors to hypothesize that settlement occurs deep on the continental slope with subsequent up-slope migration during ontogeny. As noted by A. Hines, one alternative hypothesis is that settlement occurs across the slope followed by higher natural mortality of juveniles (e.g., from predation) at shallower depths. Another possibility, derived from comments by W. Van Heukelem concerning juvenile growth rates at different temperatures, is that crabs which settle into deeper zones are locked into juvenile size classes for many more years and are, therefore, more likely to appear in samples, given low recruitment rates and markedly different growth rates across the bathymetric range of a species. What are the settlement patterns of geryonid crabs with respect to depth? What are the subsequent development and mortality rates, and how do they vary across depths?

Similarly, if larval transport by surface currents as proposed by Kelly et al., R. Smith, and Lindberg et al. is confirmed, to what extent should we expect settlement to be concentrated geographically or with respect to hydrographic features?

In general, growth rates (increments and molt frequencies) and age at first reproduction are poorly known for geryonid crabs. Accurate, detailed molt staging should be incorporated into future sampling regimes, while controlled laboratory experiments to test effects of ecological variables are particularly desirable.

A terminal molt with mating in the hard condition was suggested by G. Hinsch based on histological analyses, but this was countered by R. Smith, R. Erdman et al., and H. Perry et al. with field data and direct observations of captive pairs. As noted by A. Hines, resolution of such questions is possible with careful attention to detail, e.g. the occurrence of limb buds on ovigerous or post-spawning females.

At the population level, C. fenneri exhibits an seasonal reproductive cycle, C. maritae year-round reproduction, and C. quinquedens a protracted seasonal to continuous reproduction perhaps dependent on geographic location. Why should some geryonid species or populations show circannual periodicity while others do not? Regardless of cyclic or acyclic reproduction, only a low percentage of females are ovigerous, or pre- or post-molt at any given time, suggesting that individual reproduction is not necessarily annual. R. Erdman and N. Blake hypothesized a biennual reproductive cycle for individual female C. fenneri, while A. Hines suggested reproduction on an annual cycle or longer contingent on adequate energy reserves. Comparative studies and experimentation are needed to resolve questions of this basic life history trait.

R. Elner et al. and H. Perry et al. reported that copulation and mate guarding lasted many weeks for C. quinquedens and C. fenneri, respectively. When combined with a potentially low incidence of receptive females, this indicates extreme levels of intrasexual competition among males for mating opportunities. Lindberg et al. inferred seasonal shifts in the bathymetric ranges of male and female C. fenneri, and that large males carried mated females downslope to strata with low population densities to avoid competing males and minimize disturbance during mating. Seasonal movements, encounter rates among potential mates and competitors, movement by mated pairs, and takeover attempts all need to be documented to test geryonid mating strategies.

Geryonid species apparently differ in habitat preferences, with consequences to overall ecological comparisons and linkages to physical processes. The red crabs C. maritae and C. quinquedens have been found exclusively on soft bottoms, while Lindberg et al. and Wenner et al. reported greatest densities of golden crab, C. fenneri, from hard bottom habitat. R. Manning noted differences in leg dactyl structure consistent with weight distribution on soft bottom versus climbing ability on hard bottom topography. R. Henry et al. found that C. quinquedens were slightly more tolerant to hypoxia than C. fenneri. Whitlatch et al. attributed substantial bioturbation of soft bottom to the activities of C. quinquedens. Basic ecological questions concerning physiological ecology, refuges and foraging habits, trophic dynamics and community relationships remain largely unanswered. Given the predominance of geryonid crabs on the upper continental slope, resolution of these questions should illuminate much about general slope ecology.

Related to foraging habits of these crabs, trapping efforts have been successful despite low population densities revealed through submersible transects. Geryonids apparently exhibit particularly keen chemosensory and orientational capabilities, and great motility. This and habitat relationships raise questions about home ranging versus nomadism among species, and the relative importance of bonanza food falls versus benthic predator-prey relationships. The practical consequences of such questions concern effective areas fished by traps and the resiliency of fishing grounds to persistent fishing pressure.

The questions above pertain mostly to life history strategies and fundamentals of geryonid ecology. In part, this reflects interests of the workshop organizers, many participants, and fisheries interests. Equally valid, however, are questions of basic physiology of deep-welling organisms, biogeography and systematics, or parasitology and symbiosis. Regardless of discipline, the recent systematic revisions within Geryonidae by R. Manning and Holthius reveal taxa ripe for comparative studies.

Industry needs for harvesting, processing and marketing information have been addressed with modest research not thoroughly covered in this workshop. Nevertheless, these areas, plus basic economic considerations, could and perhaps should be compiled with existing biological data into a draft fisheries management plan for Geryonid fisheries of the southeastern United States.

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