Shellfish Committee

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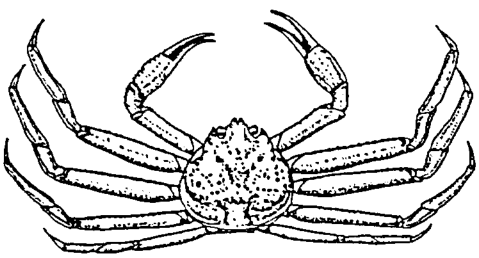
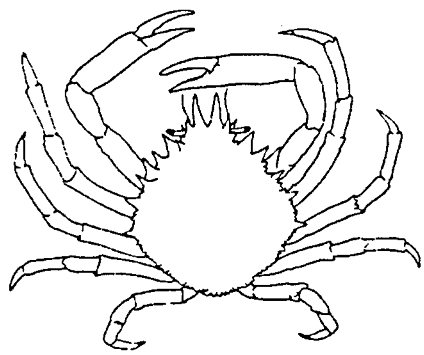
REPORT OF THE STUDY GROUP ON THE BIOLOGY AND LIFE HISTORY OF MAJID CRABS

La Coruna, Spain

20–23 November 1995





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International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK–1261 Copenhagen K Denmark

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Background to the Study Group

The decision to create an ICES Study Group on the Biology and Life History of *Majid* Crabs (SGCRAB) was made in 1992. The original terms of reference assigned to SGCRAB were to: examine similarities and differences in life history of *Majid* crabs, consider whether their life history posed special assessment and management problems, review the current status of the fisheries and provide guidelines for managers. The first meeting was held at Jersey (Channel Islands) 19–21 May 1993. The results of the SGCRAB discussions are summarized in its 1993 report (ICES CM 1993/K:3). At that meeting, SGCRAB considered the following topics:

- **life history comparisons** of spider crab *Maja squinado* and snow crab *Chionoecetes opilio*;
- **exploitation**, a review of the spider crab and snow crab fisheries in France, UK including Channel Islands, Spain, Newfoundland, Estuary and Northern Gulf of Saint-Lawrence, Southern Gulf of Saint-Lawrence;
- **assessment methods, management** (current regulations and their rationale, Majid biology and management strategy);
- **future research and recommendations for a further meeting.**

C.Res.1994/2:42 adopted by the ICES Council at its 82nd Statutory Meeting stated that the Study Group would work by correspondence in 1994 and have a four-day meeting in La Coruña, Spain, in 1995.

1.2 Terms of Reference

The terms of reference assigned to the SGCRAB for its 1995 meeting are as follows:

a) augment the present geographical comparison of life histories by including new species and areas;

b) identify nursery areas for the various species in the ICES area and establish survey protocols;

c) investigate biological reference points for management and assess the possible genetic effects of size-selective harvesting;

d) assess the future production potential of spider crabs in Europe, taking into account the factors affecting quality.

Taking account of available data during the meeting it was decided to produce the final report following this plan:

- Overview of the fisheries
- Geographical comparisons of life histories
- Fluctuations in population abundance and possible causes
- Assessment of future production potential
- Fishery selection implications
- Recommendations and conclusions

2 PARTICIPANTS AT THE 1995 MEETING

D.B. Bennett, MAFF, Fisheries Laboratory, Lowestoft, UK
S.F. Bossy, DAF, Jersey, Channel Islands, UK
Y. Chiasson, Department of Fisheries and Oceans, Moncton, New Brunswick, Canada
R. Dufour, Department of Fisheries and Oceans, Maurice La Montagne Institut, Mont-Joli, Québec, Canada
J. Freire, Department Bioloxía Animal e B. Vexetal, Universidade da Coruña, Spain
E. González-Gurriarán, Department Bioloxía Animal e B. Vexetal, Universidade da Coruña, Spain
G.S. Jamieson, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, British Columbia, Canada
D. Latrouite, IFREMER, Centre de Brest, Plouzané, France (*Chairman*)
D.M. Taylor, Department of Fisheries and Oceans, St. John's, Newfoundland, Canada
M.J. Tremblay, Department of Fisheries and Oceans, Halifax, Nova Scotia, Canada

3 OVERVIEW OF THE FISHERIES

A review of spider and snow crab fisheries was presented in the 1993 Study Group report (ICES CM 1993 K:3). The following overview is restricted to a presentation of the fisheries data and includes the previously unreported fishery of *Chionoecetes* in British Columbia, Canada.

3.1 Spider crab *Maia squinado*

Based on FAO Yearbook of Fisheries Statistics for the years 1974 to 1992, total landings of spider crab have ranged from a maximum of 11 849 tonnes (t) in 1977 to a minimum of 3 699 t in 1990 (Table 1). Most catch is from area 27 (northeast Atlantic) with little from area 37 (Mediterranean). The last two documented years, 1991 and 1992, show an increase in landings from an average 3 668 t for 1988–1990 to 5 381 t in 1991–1992. The reliability of FAO landing statistics for spider crab is known to be poor (as are most national statistics on this species), but personal observations of experts attending the meeting confirm an increase in stock abundance during these years.

3.1.1 France

According to official data, French landings for spider crab were 1 457 t in 1989, 2 504 t in 1990, 3 963 t in 1991, 3 700 t in 1992, 3 506 t in 1993, and 2 843 t in 1994. Unfortunately national landing figures strongly underestimate reality and in some cases don't even reflect the observed trend. A better indication for trend in stock abundance is expected from restricted areas where landings were correctly registered (i.e., Morlaix District for north Brittany, Le Croisic Auction Market for Biscay Bay). Such data indicate a considerable increase in landings for the 1991–1993 period. Direct recruitment estimation carried out annually (IFREMER dredging surveys before fishing season) had forecast the arrival of strong year-classes. This increase in landings has not only been observed in the western English Channel but also along the entire French Atlantic coast where stocks have been depleted for 15 to 20 years. There is a temptation to explain the occurrence of strong recruited year-classes by a succession of mild winters and springs, but no quantitative analysis has been carried out. Furthermore, recruitment indices and landings were low for 1994 and 1995, although no severe winters occurred.

Regarding crab management in France, owning a licence is compulsory for crab and lobster fishing (one licence for both crab and lobster), but currently there is no restriction on the number of licences. Due to a drastic increase in the number of pots (parlour pots) of some western Channel vessels, the decision has been made in Brittany to limit the number of pots to 200 per crew member, with a maximum of 1 000 pots per boat. A similar decision is expected to be taken soon in Basse Normandie. A six-week closed season for spider crab in the western Channel fishery is implemented annually for French fisherman.

3.1.2 England and Wales

The landings of spider crab *Maja squinado* from England and Wales reached 1 303 tonnes (t) in 1994, the second highest since the fishery began in 1979 (Table 2). The majority of these landings came from the English Channel, being split almost equally between the eastern (VIId) and western (VIIe) Channel, with the rest being caught off north Cornwall (VIIf). The landings have fluctuated between 270 and 1 517 t over the period 1979–1994. However, as spider crabs are not subject to TACs and quotas, their landings are not conscientiously recorded and the figures are unreliable. The catch rates of spider crabs have been increasing along the English Channel coast, particularly at the eastern end. Spider crabs do seem to be sensitive to low temperatures. They are reported to have died out off the southeast coast of England after the severe winter of 1962/1963 (fishermen's observation) and merchants have reported high mortalities in storage tanks during cold winters. It has been hypothesized that the recent run of relatively mild winters has resulted in an increase in stock abundance in South Wales, North Cornwall, and along the Channel coast. The distribution of spider crabs appears to have extended eastwards along the coast to the Dover Strait. Potters have been targeting them, and sole netters have been complaining about the mess they make of their nets.

The only crab management is via the EU size limit, which is set at 120 mm carapace length (CL). As the terminal moult of puberty can occur over quite a large size range, some quite large, greater than minimum legal size (>MLS) males are immature, and conversely some small females (<MLS) are mature. There have been some marketing problems with immature spider crabs, although they are larger than 120 mm CL and can be legally landed, they have not been acceptable for market and have been rejected.

3.1.3 Spain

According to official statistics, spider crab landings peaked in the 1950s and 1960s (300 t and 250 t, respectively). A sharp decrease occurred between 1965 and 1975, then from 1975 to 1985 catches fluctuated between 118 t and 60 t. From 1985 to 1993, catches increased slightly, representing 110 t in 1991 and 1992, and 157 t in 1993. Catches from

Galicia (northwest Spain) represented 65% to 85% in weight and 68% to 86% in value of the national total. These official data considerably underestimate the actual catches but they could reflect their real trend.

The fishery is carried out mainly with tangle nets but there is a small scale fishery with pots and glass-boxes in some areas. Current management regulations are based on a minimum landing size (EU size limit = 120 mm CL), with closed seasons and protection for berried females. However, these measures are not always respected by fishermen.

3.2 Snow Crab *Chionoecetes opilio*

3.2.1 Estuary and northern Gulf of Saint Lawrence snow crab

The estuary and northern Gulf of the Saint Lawrence region (fishing zones 13, 14, 15, 16, 17) stretches from Tadoussac to the Strait of Belle Isle on the north shore and from Trois Pistoles to Rivière à Claude on the south shore. The region was extended eastward toward Blanc Sablon and westward toward Tadoussac and Trois Pistoles between 1983 and 1985. The number of snow crab fishing licenses for the estuary and northern Gulf has been 136 since 1986. Snow crab are fished using different trap types, the most popular one being the Japanese trap, which are set individually or in groups.

Two management approaches have been in use since 1983. The first is based on a minimum legal size of 95 mm CW and control of fishing effort through limits on the number of licenses, vessel size and fishing season, and limits on the number, size, type and mesh size of traps. The second approach is to limit catches by a system of overall or individual quotas. Since 1994, management by quota has been the practice. In addition, since 1985, the proportion of white crab permitted in catches in all fishing areas has been limited to 20%; exceeding this level results in the immediate closure of the areas concerned.

The fishery started in the mid-1960s but remained at a relative low level until late 1970s, when landings increased from 645 t in 1979 to over 5 800 t in 1985 (Sainte-Marie and Dufour, 1995; Dufour, 1995). Landings then decreased to 2 622 t in 1989. This decrease was mainly due to reduced landings in lower North Shore areas. Landings picked up again in 1990 to nearly 4 500 t and remained relatively stable until 1992, then increased in 1993 when fishing restarted on the lower North Shore. Landing increased by approximately 35% in 1994 to 7 203 t, due to an increase quotas in four of the five fishing zones, and remains at about the same level in 1995.

3.2.2 Southern Gulf of Saint-Lawrence snow crab

The quota for zone 12 fishery (Tables 3 and 5) increased from 14 500 t in 1993 to 20 000 t in 1994, for a landed value of 125 million Canadian dollars. In 1995, 320 allocations were given to fish 4 500 t of the overall quota (20 000 t), which was fished by 131 vessels of less than 13.6 meters. The remaining 15 500 t was fished by the traditional 130 boats.

The quota for the Prince Edward Island fishery (zones 25/26) (Tables 4 and 5) was increased to 1 000 t in 1994 but after landing 923 t, the fishery prematurely closed because of a high percentage of soft crab in catches. In 1995, 200 t of the overall quota (1 000 t) was given as 22 allocations and was fished by 10 vessels of less than 13.6 meters. The remaining quota was fished by the traditional 30 vessels.

The zone 18 fishery quota (Tables 4 and 5), which stayed the same in 1994 and 1995 (749 t) was fished by 30 vessels in 1994. In 1995, 109 t of this quota was fished by 37 allocation holders using 25 boats.

3.2.3 Atlantic Nova Scotia snow crab

Snow crab are near their southern limit on the Atlantic coast of Nova Scotia. The fishery began there in the late 1970s, with landings of 1 634 t in 1979. Landings then dropped sharply and by 1985 commercial extinction appeared imminent. Stocks were thought to be unproductive due to marginal snow crab habitat and little endemic recruitment. In 1986 a pulse of pre-recruits entered commercial catches and total landings rose sharply from 1989 to 1993 when peak landings were observed (2 016 t). Landings in 1994 and 1995 were approximately 1 560 t.

Analyses of catch rate, spatial distribution of effort, biomass, and population structure for the period 1978–1993 (Tremblay *et al.*, 1994) indicate that the increased landings after 1986 resulted from three factors:

i) increased abundance and biomass;
ii) expanded fishing area;
iii) increased total effort.

Possible explanations for the increased biomass include better environmental conditions (temperatures were below long-term averages from 1985 onwards), and reduced predation from groundfish (since these stocks declined in the 1980s on the Scotian Shelf).

3.2.4 *Chionoecetes* in British Columbia, Canada

Two species of the majid crab genus *Chionoecetes* occur in British Columbia, *C. bairdi* and *C. tanneri*, both of which are referred to by the common name of tanner crab. *C. bairdi*, a species extensively exploited in the southern Bering Sea, is at the southern end of its geographical distribution in British Columbia, where it occurs on the continental shelf and in coastal inlets at a depth generally less than 200 m. It is occasionally caught as bycatch in the prawn *Pandalus platyceros* fishery, but has on occasion been more extensively exploited in British Columbia in small, directed fisheries when local concentrations are found. These concentrations occur sporadically, mostly in northern British Columbia, and presumably represent unusual settlements of substantial numbers of larvae in a specific location, probably resulting from larval drift from more substantial, southeastern Alaskan *C. bairdi* populations. These concentrations do not seem to be sustainable in British Columbia, and so tend to be exploited extensively, with no minimum size limit regulation in effect.

In contrast, *C. tanneri* appears to be consistently abundant in British Columbia, although the habitat in which it occurs is relatively limited in area. This species occurs in abundance only along the continental slope at a depth range of about 580–670 m, making its spatial distribution in British Columbia a thin band about 5–15 kilometers wide extending the length of coastal British Columbia (Jamieson *et al.*, 1989). The species probably occurs in abundance at least as far south as Northern California. In 1988, a modest trap fishery for male *C. tanneri* developed for the first time in British Columbia, but this fishery collapsed in 1990 because of a glut of *Chionoecetes* product on the world markets resulting from high landings worldwide. *C. tanneri* has slightly less meat yield than other species, as its leg in cross-section is less circular than in other species, making it less attractive to consumers in a competitive situation.

With strong tanner crab demand at the present, there is considerable interest in trying to develop the British Columbia tanner crab fishery again. It is anticipated that over the next few years, this fishery will be re-established, probably using the conservative harvest protocol described by Jamieson (1989). This protocol divides waters seaward of the surf line off British Columbia into six fishing zones, with only two fishing vessels being permitted to fish each zone. The intent is to allow sufficient fishing to obtain biological data required for development of optimum management procedures, while preventing possible over-exploitation by limiting effort in the early stages of the fishery. Fishing is expected to occur mostly from fall through spring because of participation by fishers in other seasonal fisheries. There is not currently a minimum legal size limit, but fishers to date have voluntarily imposed their own size limit of 110 mm shell width based on market preference.

4 GEOGRAPHICAL COMPARISONS OF LIFE HISTORIES

4.1 Spider Crab

Research on *Maja squinado* have been mainly carried out in Brittany (France), Jersey (Channel Islands), Galicia (Spain), the Adriatic Sea and, to a lesser extent, in Ireland and England. These studies provide data on growth, reproductive biology, and migration but they are all fragmentary and don't really allow 'in depth' geographical comparisons.

Reproduction and size at maturity

Historically, authors from different areas have proposed different mating systems, especially concerning the necessity for females to copulate prior to each spawning, but it has been demonstrated in Galicia that females can use stored sperm to fertilize successive broods. In the same area, analysis of seminal receptacles and direct observation of mating have shown that mating involved hard-shelled females with gonads in the late stages of development (the possibility of mating for soft-shelled females cannot be excluded). Ovigerous females can mate, especially in the late stages of egg development. The generality of the mating scheme is accepted. In Galicia, mating occurs during the autumn migration to deep water or in wintering locations.

Differences between Galicia and the English Channel occur in the timing of the breeding periods (eight months in Galicia, six months in the English Channel), in the duration of the incubation period (~ 30 to ~ 70 days; depending on temperature) and for the number of broods per year (varies from 1 to 3). Differences in the number of broods can produce differences in annual larval production for the same level of spawning biomass. Currently, no data is available on fecundity and success of successive broods, quality of eggs and larvae, and larval production and survival.

Size at maturity is larger in southern Europe (Galicia) than in the English Channel. This could be related to differences in duration of the breeding seasons: earlier larval settlement in Galicia leads to a higher number of moults during the first year and a greater size of 0+ juveniles. Size of 0+ juveniles at the end of the first moulting period may determine the number of subsequent moults and, thus, the size and age at maturity. It may be that a part of the population cannot carry out the terminal moult at an age of 2+ years and must therefore spend one more year as a juvenile (1 or 2 more moults), attaining a larger size at maturity. This may be more important with males, as they have greater size variability than females.

Growth

Data from Brittany and Galicia for juveniles in their last year indicate that size increment at moulting decreases when body size increases, and that values of increment in size are similar in both locations (40% to 20%).

Juvenile habitat, podding behaviour

Data suggests that juveniles are restricted mostly to rocky bottoms in Galicia whereas in northern locations, high densities can be found on soft bottoms (little is known from northern Europe about activity and location of juveniles during winter).

In Galicia and in some areas of southern England, it is felt that juveniles may form pods in summer during the peak moulting season. Such aggregations are rarely seen in Brittany. The reasons for podding behaviour are not known. In Galicia it could be a way to protect against octopi (similar to shoal for fish) but this explanation does not apply to southern England where octopi are scarce. Nor can the difference in the frequency of pods between southern England and Brittany be explained.

Migrations

Available data indicate that general seasonal migration patterns of adult *Maja squinado* are similar in Galicia and Brittany, and probably off southern England where the observations are incomplete. Although there is good knowledge of the general patterns of migration, there is a lack of information on activity and habitat utilization of both juveniles and adults, and the relationship of these aspects with environmental factors.

4.2 Snow Crab *Chionoecetes opilio* from Japan, Alaska, and Canada

In North America most research activities directed at this species are conducted by investigators of government research establishments, the ultimate goal being to gain information that can assist in developing management strategies of this marine resource. The bulk of research activities along these lines have been conducted in Atlantic Canada. Alaskan research activities have largely concentrated on *C. bairdi*, a closely related and higher valued species, while Japanese studies have been more oriented to pure rather than applied research goals.

For the three areas (Japan, Alaska, and eastern Canada) comparisons of life history parameters are only possible for fecundity estimates. These estimates indicate that size-specific fecundity for all three areas is similar but highly variable. Due to extensive studies on *C. opilio* in Japan and Atlantic Canada, comparisons are possible for several areas of investigation.

Mating behaviour

Laboratory studies (Canada and Japan) and field observations (Canada) indicate that the mating behaviour of mature males and primiparous females in both areas is virtually identical. In recent years research in Canada has focused on the competency of large- and small-clawed males paired with primiparous and multiparous females.

Growth

Japanese studies have concentrated on laboratory experiments and modal analyses of catch data while studies in eastern Canada have relied on laboratory experiments, modal analyses, and tagging studies. While growth per moult has been elucidated for both areas it has been found to be highly variable between individuals. Uncertainty about an important aspect of snow crab growth, namely the proportion of the non-terminally moulted individuals that will moult in a given year, is poorly understood and cannot be predicted far enough in advance to be incorporated into management harvesting strategies. The combined problem of predicting growth per moult and the proportion of the population that will recruit to the fishery remain one of the challenges for snow crab investigators.

Gonad development and ultrastructure

Gonad development and ultrastructure have been described in detail by studies from both areas. There are no notable differences between animals from these areas.

4.3 Snow Crab *Chionoecetes opilio* from Eastern Canadian

Fecundity

Studies in the Gulf of Saint Lawrence and Newfoundland have shown that the fecundity of females bearing orange eggs is positively correlated with carapace width. Female crabs from the southwest Gulf of Saint Lawrence and the Quebec North Shore have a higher size-specific fecundity than do those from Newfoundland.

Terminal moult

The theory that the male moult to morphometric maturity is a terminal moult has recently been proven by researchers from the Gulf of Saint Lawrence. Although this phenomenon has not been demonstrated for snow crab from Newfoundland, researchers from this area accept this principle as a universal truth for this species.

Larval distribution

Limited data are available for the Gulf of Saint Lawrence and the Atlantic coast of Nova Scotia. With the exception of the west coast of Newfoundland, data on larval distribution are non-existent.

Juvenile distribution

Juvenile distribution is well-documented for the North Shore of Quebec and the west coast of Newfoundland. Studies into this aspect of snow crab distribution have been initiated on the east coast of Newfoundland but are still preliminary.

Environmental factors

The major environmental differences between the Gulf of Saint Lawrence and the east coast of Newfoundland snow crab habitat is the fact that Newfoundland snow crab are found at greater depths than those from the Gulf and at colder bottom temperatures.

Adult Movement/Migration

Tagging studied conducted in the Gulf of Saint Lawrence and the east coast of Newfoundland reveal that snow crab movement patterns are very similar in terms of distance moved during the first year following release. Tagged snow crab from the Gulf of Saint Lawrence moved approximately twice as far during the first year following release than did tagged crabs from the east coast of Newfoundland (20.3 km vs 10.7 km). Long-term observations on snow crab males tagged on the east coast of Newfoundland suggest that steep sills at the mouth of bays may act to restrict crab movement to areas within the bay. Equivalent studies have not been conducted elsewhere.

Seasonal movements for both the Northern Gulf of Saint Lawrence and eastern Newfoundland have been documented. In both areas crabs move to shallower water during the winter, returning to deep water as spring progresses. On the west coast of Newfoundland several studies have aspects of a spring mating migration from deep to shallow water.

Mating behaviour

The results of studies from both the Gulf of Saint Lawrence and Newfoundland demonstrate that the mating behaviour of crabs from both areas is virtually identical. In Newfoundland spermathecal contents of females captured during research cruises are routinely examined in order to estimate the proportion successfully mating each year.

Growth per moult

Laboratory studies in the Gulf of Saint Lawrence and laboratory and field tagging studies in Newfoundland have determined that while growth per moult is highly variable it is generally considered to be approximately 20%.

Proportion moulting

Crabs in both the Gulf of Saint Lawrence and Newfoundland skip moult. The proportion of the population doing so each year is variable and unpredictable. While examination of maxillae can predict if moulting is imminent, this technique is not useful for management purposes due to the very short time span between detection of immediate pre-moult and the moult itself.

5 FLUCTUATIONS IN POPULATION ABUNDANCE AND POSSIBLE CAUSES

5.1 Introduction

Intensive fishing pressure on *C. bairdi* and *C. opilio* in the 1980s has resulted in drastic declines of some exploited populations. However, factors influencing natural mortality, such as diseases, predation and environmental processes, may also play an important role in population regulation.

5.2 Influential Factors

Density-dependent and density-independent factors have been suggested to potentially influence recruitment variability (Dawe, 1989). The importance of density-independent processes may be more pronounced during larval development whereas the influence of density-dependent processes may be more accentuated after settlement (Jamieson, 1986; Ennis, 1989). Changes in physical factors such as water temperature and salinity are known to affect all life stages of a population. Yearly level and duration of freshwater run-off and sea ice were also found in the past as important factors in population regulation of *H. americanus* and *C. opilio elongatus* (Sutcliffe, 1973; Somerton, 1982).

In some areas, diseases have been reported to affect crab populations and, in some cases, have decreased their abundance. For instance, crab infestation by a dinoflagellate, genus *Hematodinium,* was reported to have seriously affected Bering Sea populations of *C. bairdi* and *C. opilio* in 1985 (Meyers *et al.*, 1989; Eaton *et al.*, 1989). All infected crabs die rapidly and death occurs mainly during the vegetative phase of the parasite. As in 1985, distribution of the parasite in the Alaska bairdi fishery in 1989 encompassed one-third of the subdistricts commercially fished, with some areas suffering high infestation. In 1988, distribution of the parasite in Bering Sea *C. opilio* fisheries ranged from 0 to 14 % with increasing prevalence northward. Investigations conducted in eastern Canada have showed a prevalence of the parasite in certain areas of the northern and southern part of Newfoundland. The frequency of occurrence was rather low (≤ 0.11 %), excepted in Conception Bay, where 3.7 % of sampled crabs were infected (Taylor and Khan, 1995). Monitoring of infestation levels still continues everywhere.

Female *C. opilio* can lose up to 50 % of their eggs during the incubation period (Elner and Gass, 1984). Egg loss has been attributed to both environmental factors, parasites, and diseases. Negative effects on population fecundity by these natural agents may be more pronounced in years where the abundance of spawning females is weak. Little is known about the importance of larval natural mortality on *Chionoecetes sp.* Snow crab have pelagic larvae that live between 3 to 5 months in the water column (Conan *et al.* 1992; Lovrich *et al.*, in press). Prevalent currents and circulation features are among the most important density-independent factors that influence snow crab larvae (Dawe, 1989). Settlement in favorable habitats improves survival but because it is unpredictable, larvae may have high natural mortality during their life span.

Off the west coast of Alaska, *C. bairdi* and *C. opilio* are known to be preyed upon by up to 18 species, primarily fish species (Robichaud, 1989). Cod and thorny skate are major crab predators on the east coast of Canada. Although precise estimates of predation levels on *Chionoecetes* species have never been achieved, some authors believe that it can be important (Jewett, 1978; Waiwood and Majkowski, 1984) and could be one of the major factors controlling recruitment of *C. opilio* (Bailey, 1982).

5.3 Population Recruitment Fluctuations (The case of the northern Gulf of Saint Lawrence snow crab)

Series of recruitment surveys have been conducted off the northern Gulf of Saint Lawrence since the end of the 1980s. Surveys of the Bay Sainte Marguerite snow crab population started in 1988 and have led to new knowledge on snow crab growth, reproduction, migration and population dynamics. Similar surveys were conducted in the estuary and northeastern part of the Gulf. A valuable result was an eight-year population recruitment cycle for Gulf snow crab populations (Sainte-Marie and Dufour, 1995): five years of moderate to high recruitment often followed by three years of weak recruitment (Figure 1). The weak year-class group is termed the recruitment trough and the medium to large year-class group, the recruitment wave. Historical data clearly show that there have been two recruitment troughs, in

1977–1979 and in 1985–1987, and suggest that there were two previous recruitment troughs in 1961–1963 and 1969–1971 (Table 6). The beginning of a recruitment trough in 1993–1995 can be seen from the 1991–1994 Baie Sainte-Marguerite fall survey data (Sainte-Marie and Dufour, 1995).

Two nonexclusive density-dependent recruitment processes have been proposed to explain the existence of the recruitment troughs in *C. opilio* (Sainte-Marie and Dufour, 1995; Sainte-Marie *et al.*, 1995; Lovrich *et al.*, in press). The first is intraspecific competition for space and food and relies on cannibalism among immature crabs. Instar I (CW ≅ 3.4 mm) to V (CW ≅ 14.1 mm) are cryptic and generally live in a small part of total snow crab habitat (Lovrich *et al.*, in press). Such habitat seem essential for them and may provide food and protection against predators. Saturation of this habitat by successive year-classes of recruits through a wave of recruitment increases the chances of small crab predation by larger immature crabs. Mortality rates of first instars are expected to be higher for the last year-classes of a recruitment wave. Higher recruitment to the population, and thereafter to the fishery, will not be expected until older immature crabs, instars VII (CW ≅ 26,8 mm) to IX (CW ≅ 49 mm) leave the settlement ground through their annual migration to deeper-water adult habitats. Laboratory experiments show evidence that support the hypothesis of potential high cannibalism by larger size immature on first instar crabs (Sainte-Marie, unpubl. data).

The second hypothesis explains recruitment troughs by the scarcity of post-larvae produced in years when the reproductive biomass of females is low. The observation that the spawning biomass of females reached its lowest level in 1993 and 1994 in Bay Saint-Marguerite supports this hypothesis. Rough calculations done by Saint-Marie *et al.* (1996) show that the spawning biomass of 1993–1994 females would have been largely insufficient to account for any of the strongest year-classes produced in the Bay. However, the authors postulated that fluctuations of spawning biomass of females is a consequence rather than a cause of population cycles. Fluctuations of larval abundance through time as a function of the available spawning biomass of females may, however, play an important role in the synchronism and strength of recruitment in populations spatially interrelated.

Other mechanisms put forward to explain troughs, such as, predation by cod or other groundfish species (Bailey, 1982; Waiwood and Elner, 1982; Robichaud *et al.*, 1991) and population regulation by large adult males (Waiwood and Elner, 1982; Conan *et al.*, 1992; Tremblay *et al.*, 1994), are thought to influence yearly level of abundance of specific components of population rather than to be responsible for the trough creation itself. Cycling of *C. opilio* populations is in agreement with the population dynamic theory for iteroparous invertebrates subject to density-dependent recruitment (Sainte-Marie *et al.*, 1995).

Fluctuations in pattern of recruitment to the population seem to have a significant impact on growth and maturation dynamics of snow crab (Sainte-Marie and Dufour, 1995). Data from Bay Sainte-Marguerite and the estuary and northern Gulf fishery show that males of the first year-classes of a recruitment wave are more likely to complete their terminal moult at smaller sizes (before they reach the minimum legal size), while males of the last year-classes of a wave will complete their terminal moult at larger sizes (sizes equal or greater than the minimum legal size). As a result, the average size of the commercially-caught crabs will increase during the passage of a recruitment wave if commercial size adolescent males are not caught or are discarded properly. As Gulf fisheries are regulated by TACs, this may provide a certain stability to the fishery during the passage of a trough, since a drop in crab abundance during a trough may be compensated by a gain in weight of the commercial size adults remaining on the ground after the passage of the wave. As an example, an adult male snow crab of 95 mm (CW) weighs around 356 g, compared to 652 g for an adult male of 115 mm (CW, approximate post-moult size for the 95 mm size crab), a 83% difference in weight.

Quality of crab is also affected by recruitment fluctuations during the course of a cycle (Sainte-Marie and Dufour, 1994, 1995). Carapace ageing will accentuate during the passage of a trough as a function of the time elapsed since the entrance of the last year-class of a recruitment wave. With the onset of a trough, the fishery will rely on both the ageing stock of crab and on new recruits of the year. Size of commercial crab caught will decrease during the passage of a trough and the white crab (newly moulted crab) proportion will amplify. This situation appeared in the Gulf fishery in 1987–1990 with the passage of the 1977–1979 recruitment trough.

Fishing strategies can be put forward to dampen the consequences of the passage of a recruitment trough (Sainte-Marie and Dufour, 1995). Decline in abundance of commercial size crabs can be partially cushioned by rational harvesting practices that maximize yield per recruit. Two principal measures are suggested to attain this goal:

1) never land or injure adolescent males, because they are still growing and their individual weight will increase considerably over a one- to two-year period;

2) land adult males with dirty or intermediate shells, because they have stopped growing and will degenerate rapidly to a dirty-soft condition which will greatly reduce their availability to the fishery and their quality. Conversely, males with clean shells may still be available to the fishery for another two or three years and serve as a reserve.

6 ASSESSMENT OF FUTURE PRODUCTION POTENTIAL

Many of the fundamental issues related to future yield and recruitment in majid crabs were addressed in the previous report of the Study Group (ICES CM 1993/K:3).

- Yield-per-recruit and quality would be higher if juvenile or adolescent crab (i.e., those that have not terminally moulted) and white crab are not landed.

- Yield-per-recruit would increase if a minimum legal size based on a dimension representing terminal moult status was established and enforced.

- Stock-recruitment relationships in majid crabs, like many other species, are poorly understood. In the snow crab fishery, only males are exploited and spawning stock biomass is protected. In spider crab fisheries, both sexes are fished.

- The rate and pattern of exploitation should be such that (i) crab are not harvested in a soft condition or at a juvenile or adolescent state, and (ii) there is no accumulation of large, old crabs that have lower market quality and survival.

- Both snow and spider crabs are subject to considerable recruitment variability.

Since 1993 there have been a number of research or fishery developments which are relevant to these issues.

In *Maja squinado*, new data were presented that indicate that the size-at-maturity off Galicia, Spain, is larger than in more northerly areas (see Section 4.1). As a result, it appears that off Galicia only 5% of females are able to reproduce at sizes below the minimum legal size of 120 mm carapace length. Combined with the high exploitation rates, it may be prudent to increase population egg production in this area. Egg production of spider crabs could be increased using a number of strategies. A legal measure based on female abdominal width, or an other anatomical changes associated with maturity, has potential since available data indicate a distinct morphometric separation between mature and immature females. For male spider crab, plots of claw size versus carapace length show some overlap between juvenile and terminally moulted crab.

As in other crab and lobster fisheries, the optimal level of egg production that should be protected in majid crab fisheries is not resolved. The apparently low percentage of female spider crab spawning off Galicia contrasts with the situation in snow crab, where all females get a chance to reproduce (since the fishery exploits only males). Although snow crab females are protected, there may be considerable discard mortality in areas where sorting of the catch is done below deck (e.g., some fleet components off Newfoundland). Also, snow crab eggs can take up to 2 years to develop. The clutch size of majid crab can be reduced over time due to factors such as abrasion, predation, and infection. Given the longer incubation time for snow crab clutches, these factors may be relatively more important to the population fecundity of snow crab than of spider crab.

Snow crab females are protected largely because of their small size (generally <90 mm carapace width) and low marketability. If, in the future, alternative markets for snow crab females develop (eggs, for example), scientists may be asked to provide more justification for the male only rule.

In *Chionoecetes opilio*, harvest at a less than optimal yield-per-recruit continues to be an issue. There is concern that yield-per-recruit is low in some areas because of harvesting of soft and juvenile crab. In addition, there is some "waste" of older crab which are discarded because of their low market value. A large recruitment pulse in the southern and northern Gulf of Saint Lawrence is now passing through the fishery. There is a need to target older crab with dirty shells, especially at the end of a recruitment wave, because of their shorter life expectancy compared to males with clean, hard shells. This may also help to dampen the effect of the low abundance trough which follows the wave. With the recognition that snow crab recruitment occurs in waves (see Section 5.3), in the future it may be best to increase fishery removals at the start of the recruitment wave, so that crab with older shells do not accumulate. Such a change assumes that older crab are not of special importance to reproduction; this should be evaluated.

7 FISHERY SELECTION IMPLICATIONS

A recent study of Dungeness crab in British Columbia (Jamieson, in press) suggests that fishery selection for the largest individuals in a population may be affecting species population dynamics, as many crabs just below legal size apparently are not moulting to legal size. Jamieson suggests that this could be the result of either genetic selection for slower growing individuals, or a behavioural response of individuals arising from a changed population size structure. To be anthropogenic, if crab are mating successfully at a relatively small size, there may be no biological advantage to their moulting to a larger size, and so they do not.

Other crab fisheries may also be quite size selective, particularly since relatively little mortality normally arises from the release of undesirable crab. Stock definition is important, particularly the detection and identification of discrete "gene" pools. Mitochondrial DNA work is currently underway on snow crab *Chionoecetes opilio* in eastern Canada, but studies are not yet completed. Evidence to date for discrete populations is based on morphometrics and electrophoresis (Davidson *et al.*, 1985). This has implications in the dispersal of larvae, and so such studies should have an oceanographic component. Populations in a common stock should have a broadly similar recruitment pattern and variability around this pattern. Biologically identifiable populations may exist, and it is important to know this from both research and management perspectives.

Assuming crab fisheries are selective, the nature and manifestation of this selection needs to be considered. A first step is to define the effective reproductive component of the population and to define the size range of individuals in a year-class that is contributing most to population fecundity. With *C. opilio*, the following biological and fishery aspects are relevant:

- females are not exploited;
- < 40% exploitation rate of terminal moult males, giving survivors opportunity to mate before the next harvest;
- the size at which individuals moult to a terminal moult state is likely to be density dependent;
- proportion by size of terminal moult males determines male breeding success by size.

With the spider crab *Maja squinado* relevant aspects are:

- both females and males are harvested;
- fisheries in a calendar year start before mating and reproduction occurs;
- with English Channel Maja, the largest half of a year-class does not seem to have opportunity to breed because of its heavy fishery exploitation;
- with south Galacian Maja, the largest 80% of males and largest 95% of females probably do not breed for the same reason, and many of the largest immature crab are also exploited.

Given the above, it seems unlikely that genetic selection for smaller animals or for reduced moulting probabilities for individuals is occurring in Canadian snow crab. However, it would seem quite likely that selection may be occurring in spider crab, as the fastest growing and largest crab seem to have relatively little breeding opportunity and, hence, do not contribute much to total population fecundity.

Potential long-term implications are two-fold. From a species population dynamics perspective, selection may be occurring for animals which do not exceed the minimum legal size, since few crab above this size may breed. Effects could be on moulting probabilities and/or moult characteristics. Consequences could be either smaller moult increments, producing dwarf crab, or achieving terminal moult at a smaller size. Secondly, there is a possible reduction in yield from an exploited year-class because:

- assuming present size limits remain, the proportion of a year-class that would be available to a fishery would decrease; or
- assuming the size limit was reduced to reflect a possible decrease in age at maturity, average size of crab landed might be smaller.

The most likely immmediate management implication is that poaching of sublegal crab will likely increase as fishers note the relative increase in proportion of sublegal crab present, while noting that annual legal crab catch may be declining. Trying to minimize this illegal catch could increase enforcement costs.

Because of its relatively short generation time (2 y), the spider crab appears to be an ideal species for investigating these phenomena. Options to evaluate the possibility that crab fisheries are modifying the population dynamics of the species could include:

1) adopting a metapopulation modelling approach, where population dynamics are simulated and possible biological changes incorporated;

2) comparison of the biological characteristics of exploited and unexploited, if any exist, populations (it should be noted there may be a difference in the dynamics of virgin (i.e., never exploited) and now-unexploited populations in the selection of study sites for the latter group);

3) evaluation of the need to establish refuge populations, either for study of (2) above or because conservative management suggests immediate action would help mitigate against possible selective effects in other nearby exploited populations.

8 RECOMMENDATIONS AND CONCLUSIONS

8.1 Research

Geographical comparisons of life histories show that considerable variations in both species population dynamics and exploitation patterns exist. To understand adequately how this influences site-specific yields, and to ensure conservative management is practical, more region-specific studies are needed. The following topics have been identified as a guide for future research.

- Study of early juvenile life history: small-scale study sites and refuges, settlement areas, habitat structure (bottom type, depth), movements between habitat patches (especially from settlement to juvenile areas), predation risk and related behaviour (activity, podding, etc.).
- Analysis of pre-and post-settlement factors that regulate year-class strength.
- Study the quality of successive broods and its relation with larval success.
- Determine the importance of cannibalism and resource limitations on population dynamics.
- Factors affecting when crabs reach the terminal moult; skip moulting; geographical variation in size at maturity.
- Study of migrations (physiological effects, cues and causes, orientation) and evaluation of juvenile and adult habitats (spatial structure of the population).
- Implications of migrations and spatial distribution (juveniles/adults) on conservative management (protected areas, closed seasons). Relationship between migration and catch of tangle-net fisheries.
- Identification of population units for research (and management) purposes and critical locations (habitats) for conservation refuges or for establishing priorities for mitigation of pollution disasters.

8.2 Management

The available evidence indicates that *Maja* is heavily exploited. SGRAB draws attention to the following:

- the minimum size limit is not based on biological considerations;
- both sexes are exploited;
- exploitation and poaching of juvenile and ovigerous crabs is often prevalent;
- consideration should be given to:
- basing exploitation criteria (minimum size limit, excluded cohorts (ovigerous, soft)) on biological data;

- preventing further expansion of fishing effort through restrictive licensing;
- establishing refuges (protected) areas for research and for precautionary stock-recruitment or genetic concerns.

This has been largely done in Canada for the snow crab, with extensive effort and catch limitations. There are no refuge areas *per se*, but because snow crab is a deep water species and is difficult to survey, the full geographic range is still being determined. Attention is drawn to the concern being expressed that snow crab discard mortality may be high because soft and under-sized crabs are frequently held for 1–6 hours before discarding, and released crabs are often physically damaged resulting in a presumed high mortality. Discard mortality needs to be quantified and minimized.

For spider crab and for snow crab, consideration should also be given to:

- long term impact of the present management strategies on population fecundity and genitors;
- development of abundance indices to evaluate the status of a stock on a short-and long-term basis.

8.3 Future Meetings

When discussing the necessity for a further meeting, the members of the Study Group concluded that there is considerable value in the exchange of knowledge and experience from both sides of the Atlantic and from the Pacific. It was agreed that it would be very profitable to maintain a meeting every third year on behalf of ICES, and suggested that its remit should be enlarged to include other commercially-important crab families (notably portunid and cancrid crabs) which are not covered by any ICES working or study groups at present.

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Table 1. Nominal catches of *Maja squinado* by country and major fishing area (1974–1992). Source: FAO Yearbook of Fishery Statistics.

YEAR	DENMARK	FRANCE	IRELAND	PORTUGAL	SPAIN	UK ENGLAN WALES	UK CHANNEL ISLANDS	TOTAL AREA 27	FRANCE	SPAIN	YUGOSLAVIA SFR	YUGOSLAVIA FR	CROATIA	TOTAL AREA 37	TOTAL ALL AREAS
1974		6258		52	82			6392	20		85			105	6497
1975		6119		40	229		700	7088	26	1	77			104	7192
1976		5885		46	153		750	6834	19	2	88			109	6943
1977		10623		13	132		964	11732		2	115			117	11849
1978		5605		5	92		1100	6802			36			36	6838
1979		5520		10	115		1130	6775			33			33	6808
1980		6069		30	76		1240	7415		1	34			35	7450
1981		4757		46	44		1300	6147	16		24			40	6187
1982		6531		66	119		800	7516	18		34			52	7568
1983		5298		52	82	546	428	6406	12		22			34	6440
1984		3946		60	129	1181	601	5917	13		34			47	5964
1985		3237		63	115	1240	548	5203	11		27			38	5241
1986		2921		54	150	906	428	4459	8		26			34	4493
1987		3691	180	49	122	802	278	5122	9		37			46	5168
1988		2376	190	31	113	452	485F	3648F	11		59			70	3718F
1989		2376F	200	39	113F	311	643	3683F	7		44			51	3734F
1990		2376F	198	40	127F	267	663F	3672F	6		51			57	3729F
1991		3958	150	40	117F	611	618	5495F	4		29F			33F	5528F
1992		3910F	106	42	124F	600	485	5268F	1				33	34	5302F

F = FAO estimate from available sources of information.
Area 27: Northeast Atlantic.
Area 37: Mediterranean.
No available data from Area 34 (Northwest Africa).

Table 2. Landings (tonnes) of spider crabs *Maja squinado* from England and Wales by ICES division, 1979–1994.

YEAR	VIId	VIIe	VIIf	VIIg	TOTAL
1979	93	376	1047		1517
1980	50	720	40		813
1981	69	494	286		851
1982	7	93	168		270
1983	184	190	171		545
1984	429	404	345	2	1182
1985	349	364	521	4	1241
1986	109	213	579	7	911
1987	33	196	568		813
1988	6	151	278		454
1989	3	97	208		345
1990	34	181	54	14	320
1991	52	374	141	67	663
1992	189	393	266	117	842
1993	166	241	309	51	767
1994	586	502	206	8	1303

Table 3. Snow crab from Southern Gulf of Saint-Lawrence; fisheries information pertaining to zone 12.

Catch (t)	24 267	11 782	12 355	7 882	6 950	10 019	11 235	14 336	19 995	19 930
Traps	454 657	449 293	528 844	356 442	254 578	32 6671	362 967	344 698	390 833	
cpue	53.37	26.22	23.36	22.11	27.30	30.87	30.95	41.59	51.16	

Table 4. Snow crab from Southern Gulf of Saint-Lawrence; fisheries information pertaining to zones 18, 19, 25/26.

	zone 25/26 *Prince Edward Island*				zone 18			zone 19		
	trap hauls	cpue	total catch	quota	cpue	total catch	quota	cpue	total catch	quota
1993	12 692	63.0	800 t	800 t				92.2	1 678 t	1 686 t
1993–1994					55.5	748 t	749 t			
1994	29 302	31.5	923 t	1 000 t				68.3	1 672 t	1 686 t
1994–1995					59.4	734 t	749 t			
1995			981 t	1 000 t					1 575 t	1 577 t
1995–1996						1 575 t	1 577 t			
1995			981 t	1 000 t					1 575 t	1 577 t
1995–1996						1 575 t	1 577 t			

Table 5. Snow crab landings and TAC data for the Southern Gulf of Saint-Lawrence from 1968 to 1994.

	zone 12		zone 18		zone 19		zones 25+26		TOTAL
	Catch (t)	TAC (t)	Catch (t)	TAC (t)	Catch (t)	TAC (t)	Catch (t)	TAC (t)	Catch (t)
1968	3 939								3 939
1969	2 580								2 580
1970	5 634								5 634
1971	5 374								5 374
1972	5 392								5 392
1973	6 969								6 969
1974	6 704								6 704
1975	4 632								4 632
1976	7 568								7 568
1977	9 537								9 537
1978	10 462				1 941				12 403
1979	15 794		213		1 390	1 406			17 397
1980	14 854		519		1 158	1 225			16 531
1981	21 877		494	835	913	1 004			23 284
1982	31 585		824	835	953	1 004			33 362
1983	24 342		822	835	906	1 004			26 070
1984	26 062		722	835	1 315	1 385			28 099
1985	25 158		537	835	1 234	1 385	802		27 602
1986	24 267		618	626	1 235	1 338	1239		27 359
1987	11 782		626	626	1 151	1 150	457		14 016
1988	12 355		669	674	1 337	1 338	666		15 027
1989	7 882		666	674	1 334	1 338	747		10 629
1990	6 950	7 000	662	674	1 333	1 338	546	500	9 491
1991	10 019	10 000	722	874	1 337	1 338	615	600	12 693
1992	11 235	11 200	715	749	1 678	1 686	783	800	14 411
1993	14 336	14 500	748	749	1 678	1 686	800	800	17 562
1994	19 995	20 000	745	749	1 672	1 686	923	1 000	23 324
1995	19 930	20 000	682	694	1 575	1 577	981	1 000	23 168

** The spring season in 1990 was interrupted by a conflict between groundfish and snow crab fishers, and later by the high occurence of soft-shelled crab in the commercial traps. The remainder of the spring quota was therefore taken during the autumn fishery. In 1991, a quota of 200 tonnes was allocated for the spring season and a quota of 674 tonnes was allocated for the autumn 1991 + spring 1992. Therefore, the table above indicates the spring and autumn seasons of 1991 and the spring season in 1992. Similarly, the 1992 to 1994 TACs correspond to the autumn of that year and the spring of the following year.*

Table 6. Data pertaining to the formation of the trough in the Northern Gulf fishery (middle north shore management, zone 16).

Weak recruitment periods (instar I)	1961–1963[1]	1969–1971[1]	1977–1979[2]	1985–1987[2]	1993–1995[2]
Weak landings	1971–1973[a]	1979–1981[b]	1987–1989[c]	1995–1997[d]	2003–2005[d]

1) Extrapolated periods of weak recruitment to the population.
2) Documented periods of weak recruitment to the population.
a) After an intense fishing period from 1969–1970, exploitation resumed in 1972 after landings drastically dropped in 1971.
b) Slight landing decrease in 1981 after a gradual and moderate restart of the fishery in 1977, but marked dropped in the cpue from 1980 (37.5 kg/trap) to 1981 (10.8 kg/trap).
c) Landings decrease of 29.5% from 1986 (2 254 t) to 1989 (1 590 t), cpue dropped of 24.7%.
d) Anticipated period of weak landings and (or) cpue.

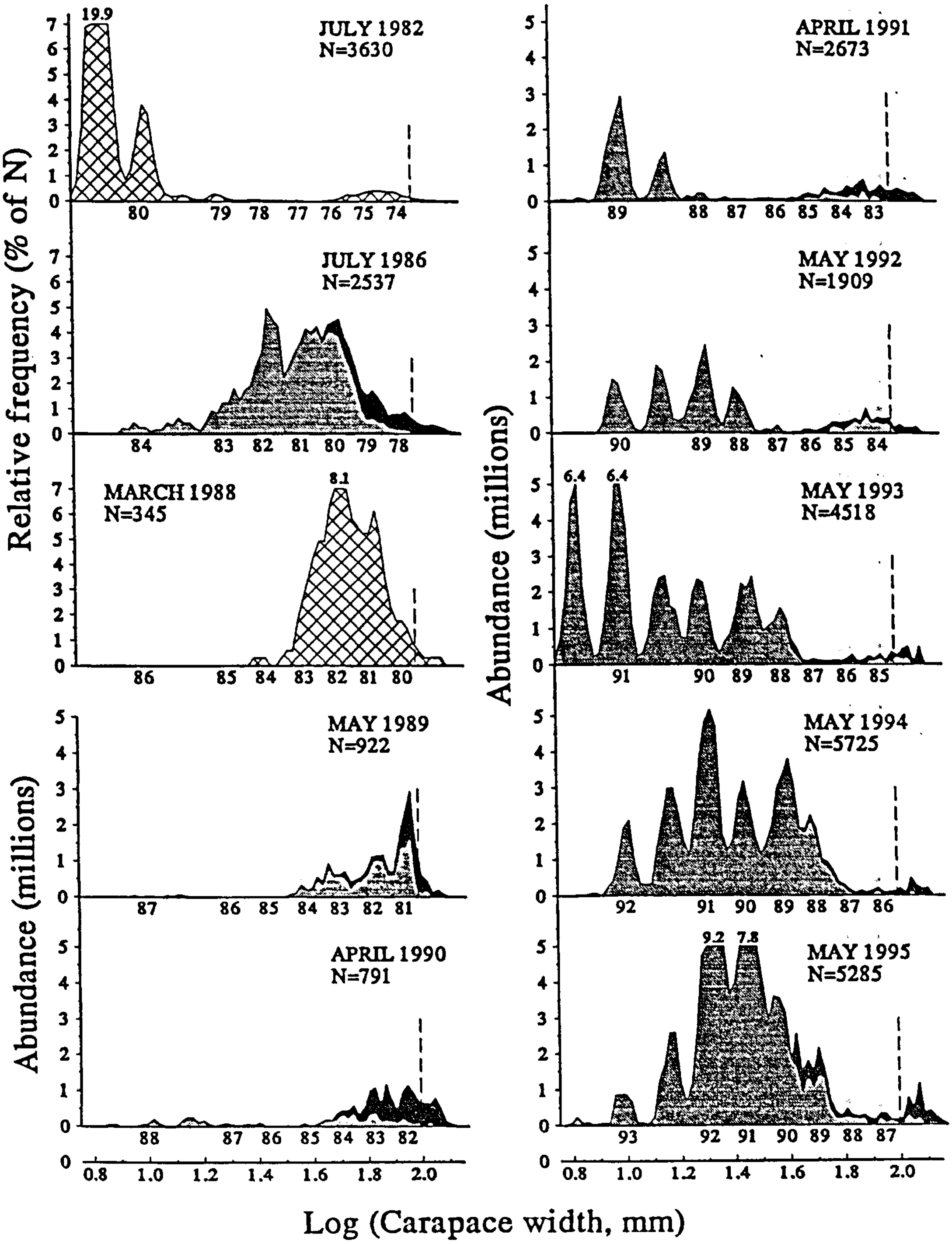

Figure 1. Size structure of male *Chionoecetes opilio* in the Baie Sainte-Marguerite population from 1988 to 1995 and in the neighboring Rivière-au-Tonnerre population in 1982 (Brêthes *et al.*, 1987) and 1986 (Dufour, unpublished data). Hatched areas represent males of unspecified maturity, grey areas represent immature and adolescent males, and black areas represent adult males. Size frequencies for non-quantitative surveys conducted from 1982 to 1988 and for quantitative surveys conducted from 1989 to 1995 are presented respectively as the relative frequency of crabs and absolute abundance of crabs per size classes of 0.02 units of log10 carapace width. Number beneath modes represent year-classes, occasional numbers above modes represent maximum frequency or abundance, and the vertical dashed line represents the minimum legal size of 95 mm carapace width. Modes to which no year-class is assigned are composed of crabs belonging to either or both of the year-classes assigned to flanking modes.