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Field use of an injected ferromagnetic tag on the snow crab (*Chionoecetes opilio* O. Fab.)

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This paper describes a crab tagging method with a potential for retention during ecdysis. Miniature ferromagnetic tags are injected mechanically into the dactylus of crab legs and are recovered in commercial landings using a magnetic detector. The method was tested in the field and shown to be practical for the rapid tagging of large numbers of crabs at sea. A statistically valid estimate of stock size was calculated.

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Introduction

Tagging is a fundamental tool in the study of growth and population dynamics of Crustacea. In contrast to most fish species, crustaceans are impossible to age individually, owing to the absence of age-related marks in the hard structures, which are lost regularly at ecdysis. Another consequence of ecdysis is the loss of the tags attached to the exoskeleton. The development of permanent tags is thus essential for the study of growth, long-term mortality, and movements.

Different kinds of permanent tags have been developed for different species of Crustacea. In Anomura, such as the king crab, and in Macrura, such as the lobsters, tags can be inserted around or into the dorsal musculature at the junction between the cephalothorax and the abdomen (Gundersen, 1962; Gray, 1964, 1965; Scarratt and Elson, 1965). At ecdysis, the covering membrane is torn by the tag, which remains attached to the animal.

Brachyura require a different tagging approach because they do not have such an exposed dorsal musculature. Crabs of the genus *Cancer,* for instance, can be permanently tagged with a suture tag threaded through two holes punched in the carapace along the epimeral suture, which splits during ecdysis (Butler, 1957; Edwards, 1965).

However, not all crabs have a well-defined epimeral suture. Crabs of the genus *Chionoecetes* are particularly difficult to tag permanently. Tagging studies in the field have generally involved non-permanent tags (Tanino and Ito, 1968a, 1968b; Watson, 1970; Watson and Wells, 1972; Meyer, 1974). Experiments on a permanent tag have obtained some success with a plastic anchor tag inserted under the rear edge of the carapace (Fujita and Takeshita, 1979; Taylor, 1982; McBride, 1982). This technique is similar to the suture tagging method used for *Cancer* spp. crabs, but the tag is not retained as effectively and may interfere with the moulting process.

An injected micro-tag (Jefferts *et al.*, 1963) seems a promising approach to the problem of permanently tagging crabs of the genus *Chionoecetes.* The tag can be easily and entirely implanted into internal tissues. If properly placed, it should not be lost at ecdysis when the exoskeleton is cast off. A magnetic detector must be used to retrieve the magnetized stainless-steel tag. This method is already successfully used with fish (Bergman *et al.*, 1968; Durkin *et al.*, 1969; Ebel, 1974; Winters, 1977; Corten, 1980; Opdycke and Zazac, 1981; Krieger, 1982). It has also been tested in aquaria on crustaceans such as shrimp (West and Chew, 1968; Prentice and Rensel, 1977), lobster (Wickins and Beard, 1984), and crab (Tutmark *et al.*, 1967). The only field study on crustaceans was by Ennis (1972), who used the tag to measure the growth of *Homarus americanus.*

We describe a field experiment with this injected ferromagnetic tag in a large-scale study of a population of snow crab. The objectives were to develop and test a method to tag large numbers of specimens at sea, in order to obtain information on population size, rate of exploitation, and eventually, growth. Preliminary results are presented.

Snow crab (*Chionoecetes opilio* O. Fab.) (Oxyrhyncha, Majidae) is common on the east coast of Canada. It is found on muddy substrates in cold waters (−1° to

+3 °C), at depths ranging from 70 to 150 m in the Gulf of St. Lawrence. A fishery has developed since 1967, and exploits only males above a minimum size of 95 mm (carapace width).

Materials and methods

Tagging equipment

The tagging system used consists of an MK III injector, a power supply box (operated by 120 volt AC current), a touch switch, a magnet, and a battery-operated field sampling detector (supplier: Northwest Marine Technology, Shaw Island, Washington, USA). This equipment is portable, light, and compact. The tags are 2-mm lengths of stainless-steel wire, 0·356 mm in diameter. More details on the equipment and its field use are available in a study by Koerner (1977).

Experiments in tanks

The tagging procedure was developed on snow crabs ($n = 10$) kept in sea water at a temperature never exceeding 5 °C. The tagged crabs were kept under observation for up to four months. Only one crab initiated ecdysis but died in the process.

Tagging procedure

The dactylus of a walking leg was selected for implantation of the small tag. This location eliminates the difficulty of puncturing the hard exoskeleton since the tagging needle is simply inserted through the articulation membrane. Leg tips are also convenient to place in the aperture of the magnet for magnetization and along the groove of the detector when testing for magnetization and for recovery. After a tag is detected, the dactylus can be preserved for later extraction of the tag under a dissecting microscope, which is easier than if the tag were implanted in a larger cavity. All vital organs are avoided and since no meat is extracted from this part of the crab, the risk of accidental human ingestion of unrecovered tags is eliminated.

Size-class identification

Tagged crabs cannot be individually identified with this system since a spool of tagging wire has the same binary code etched along its entire length. This may be a handicap for growth studies in which the initial size must be known. A partial solution to this problem is to assign a different size class to each leg, following a pre-established convention (Fig. 1), and to tag each crab in the leg corresponding to its size class. Crabs missing the assigned leg are tagged with a different wire in the first pereiopod on the same side. Three differently coded spools are used, one for each possibly missing pereiopod. If both the assigned and the alternative pereiopods are missing, the tag is injected in any leg on the corresponding side. This procedure enables any crab being released to be assigned to one of six different size classes, with minimal time-consuming changes of wire.

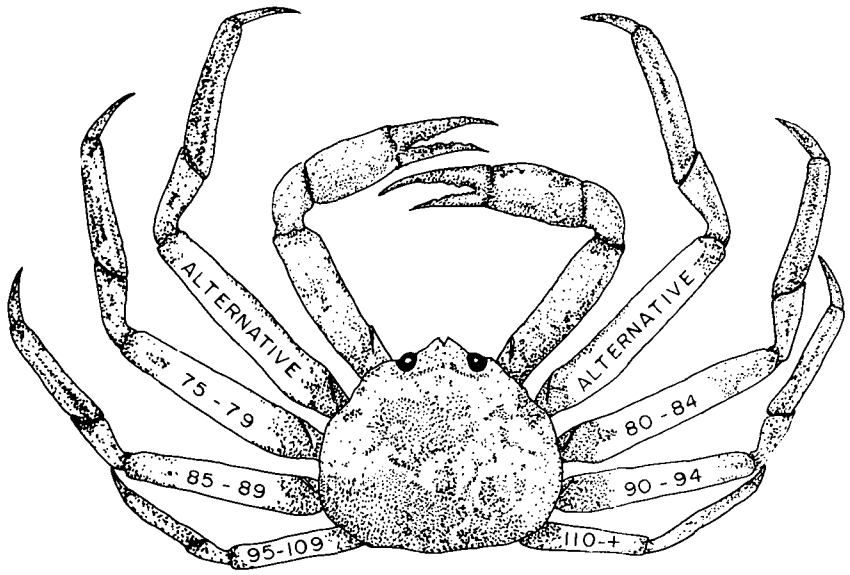

Figure 1. Pereiopods selected to identify the size class (mm) of each crab at the time of tagging. Alternative pereiopods replace a missing one on the same side.

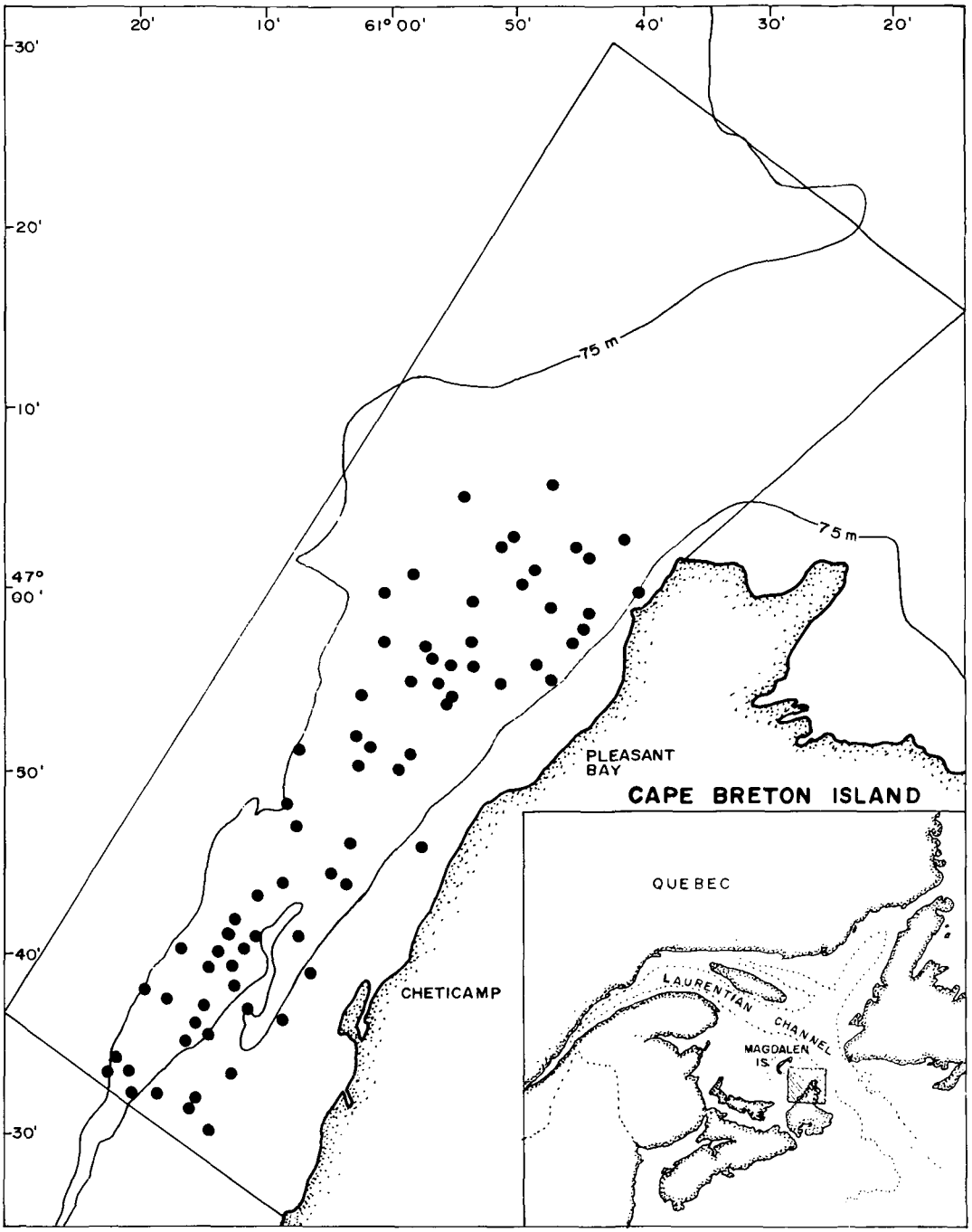

Figure 2. Study area and distribution of the tagging stations over the known fishing grounds, lying mostly within the 75-m isobath. The straight lines in the main diagram delineate the extent of the administrative fishing zone.

Experiments in the field

The micro-tag was tested in an area of approximately 4000 km^2, located northwest of Cape Breton Island, Nova Scotia (Fig. 2). This area is bordered to the north by the deep Laurentian channel and to the west by the sandy Magdalen shallows. The southern limit was set by fishery management to separate it from another fishing area. The total allowable catch for 1983 was 1000 tonnes. Each of the 27 boats licensed to fish this area

was entitled to a 37-t quota. The fishing season started on 15 July and quotas were reached within seven weeks.

Crabs were fished by traps set for 48 hours at 73 randomly selected stations (Fig. 2). Tagging was carried out from 10 to 18 June 1983. Each male snow crab captured was measured, tagged, and released in the vicinity of its capture site. This procedure ensured that the distribution of the tagged crabs approximated to the distribution of the whole population (Seber, 1982). A staff of five persons quickly tagged and returned each crab in the water. Care was taken not to expose the crabs to rough treatment or direct sunshine, and ice was used on warmer days to keep the crabs in cool moist air. Some crabs were double-tagged with a highly visible yellow vinyl tubing tied around the cephalothorax. Fishermen were requested to return these double-tagged crabs for a check on the retention of the magnetic wire tag.

Recoveries started at the beginning of the fishing season (16 July) until 5 August 1983. Three teams of two persons were sampling the daily landings in Chéticamp and Pleasant Bay. Upon arrival of the boats at the wharf, between noon and 20:00 h, an effort was made to inspect as many crabs as possible for tags, as they were unloaded. Legs from both sides of the crabs were passed at least twice above and as close as possible to the detector without touching its aperture. The presence of a tag was easily confirmed by a clear whistling signal. The tagged dactylus of the recaptured crabs was individually frozen and all relevant information recorded. The tags were later removed and identified under a dissecting microscope.

Data analysis

The Petersen method is the most appropriate for estimating population abundance from the data of our single mark-recapture experiment. Underlying assumptions of the method are discussed in great detail by Ricker (1975) and Seber (1982). The main ones are: (1) the population is closed, so that N is constant during the experiment; (2) the tagged crabs are randomly mixed in the population; (3) the crabs do not lose their tags during the experiment; (4) all tagged crabs are detected on recovery; and (5) the tagged and untagged crabs have the same probability of being caught in the recapture sample.

The population size was calculated by the following modified estimator (Ricker, 1975).

$$N = \frac{(M + 1)(C + 1)}{R + 1}$$

where M is the number tagged and released,
C is the number examined for tags in the landings,
R is the number of tags recovered in the sample C, and
N is the estimate of the total population.

For management purposes, it is advisable to aim for a Petersen estimate that has 0·95 probability of being within 25 % of the true population size (Robson and Regier, 1964). This goal can be achieved by various combinations of number tagged and number examined for tags. These combinations of values are calculated by a long iterative procedure but are more conveniently obtained from figures prepared by Robson and Regier (1964).

Results

Tag retention

From a total of 235 crabs released with a double-tag, 29 were recovered. Unfortunately, one had lost its tagged leg during handling on the fishing vessel. In only one case was the implanted tag not found in the dactylus.

No unfavorable reactions have been noted for crabs kept in captivity. Some bruising of the tissue due to the insertion of the injector needle and to the presence of the tag was observed. This was indicated by a dark coloration around the tag and near the membrane where the needle was inserted. This dark coloration appeared in all crabs kept in captivity within the first few weeks after tagging and remained stable for the following months of observation. Only 31 % of the tagged crabs recovered in the field had some indication of such bruising. No crab in captivity autotomized a leg in reaction to the tag and motility was unaffected.

The crab that died while moulting during the observation period in the tank was dissected to investigate the retraction of the new cuticle from the old one. Figure 3 illustrates the position of the tag inside the tissue of the dactylus and shows how the tag would be retained in the animal after ecdysis.

None of the crabs recovered seem to have moulted after they were tagged. The few soft-shelled crabs (approximately 1 %) observed in the landings were present in the last week of the recovery, indicating that there had been virtually no moulting between the tagging and recovery periods. Consequently, the method was not tested for retention during ecdysis.

Tagging and recovery

All healthy male crabs captured at sea were tagged. In a single day, up to 1023 crabs were tagged. However, the tagging was restricted by the availability of crabs, which was in turn limited by the number of stations fished in a day and by the numbers caught in each trap. Given an unlimited supply of crabs, the tagging team could easily have released between 1000 and 2000 tagged crabs per day. Operations were also slowed by the frequency of usage of the special wire spools, but this was a minor problem since only 5·3 % of the total crabs were missing the appropriate leg.

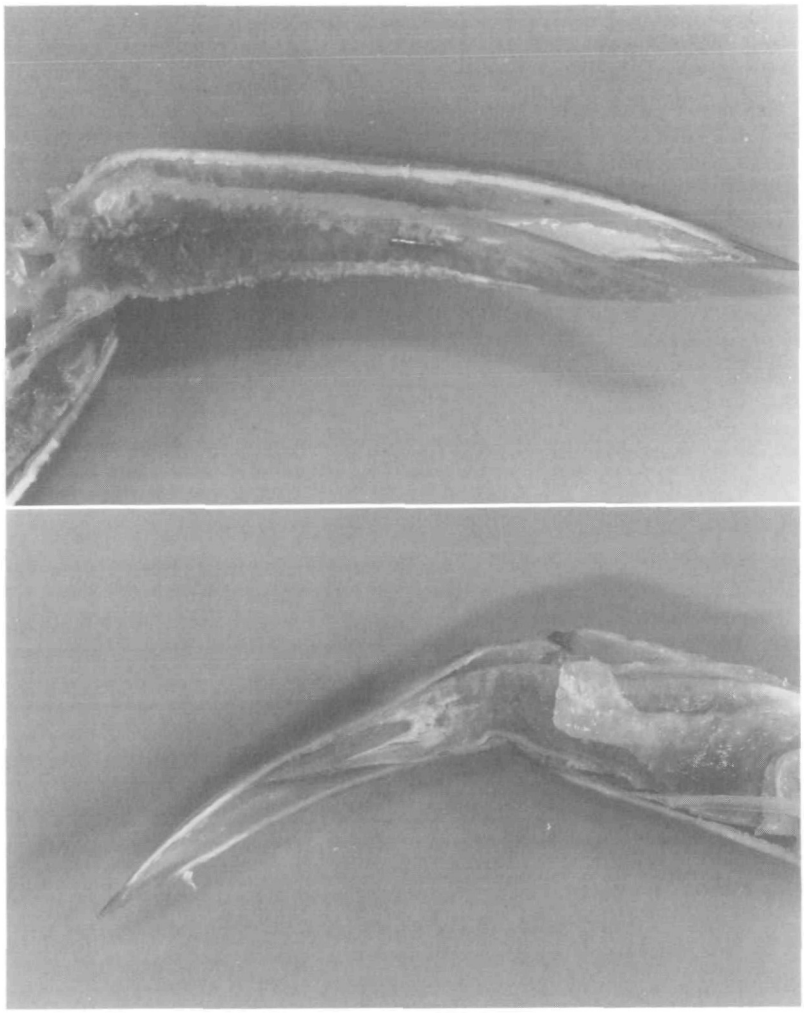

Figure 3. Longitudinal sections of snow crab dactylus at ecdysis showing: (top) the ferromagnetic wire-tag implanted in the tissue, and (bottom) the retraction of a dactylus from the old exoskeleton.

A total of 4967 crabs were tagged during the eight days of fishing. Of these, 308 crabs (6%) were below the legal size limit of 95 mm (CW).

A total of 109534 crabs were examined in the landings, and 83 tagged crabs were detected (Table 1). The maximum number examined in a day (10262 crabs) reflects the maximum working capacity of the three teams combined. The daily recovery rate fluctuated around an overall average of 7·6 recoveries per 10000 crabs examined (Fig. 4). The cumulative data show that after ten days of effort, the average recovery was already stabilized near the final value. Further sampling increased the precision of this estimate, which represents the proportion of tagged animals in the total stock.

Stock size

Only crabs with a size of 95 mm (CW) and above were

Table 1. Results of the detection effort.

Date		Number examined	Number recovered	Total cumulative landings (kg)
July	16	8564	9	
	18	4882	3	
	19	8371	3	
	20	8671	6	
	21	10262	8	181942
	22	5909	6	
	23	5430	2	
	24	4657	10	
	25	8718	5	
	27	9652	9	
	28	8150	5	496770
August	1	9307	8	
	3	8899	5	
	4	4694	3	709844
	5	3370	1	
Total		109534	83	905560

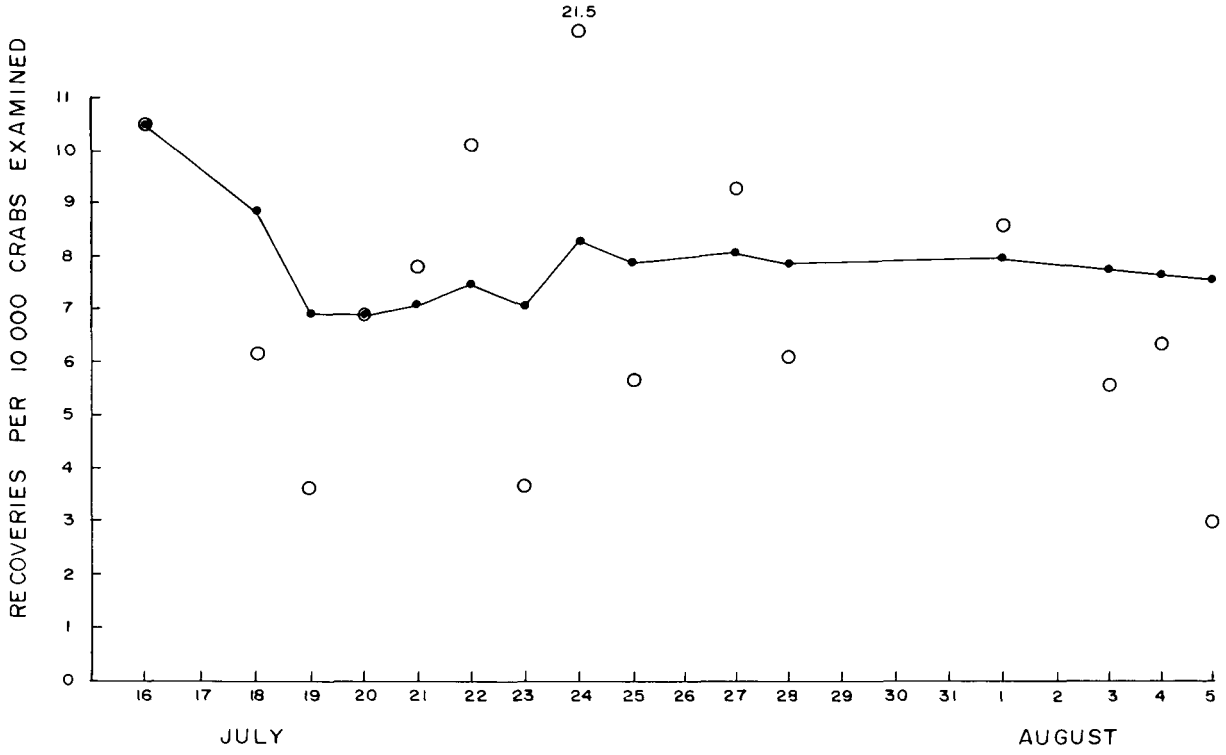

Figure 4. Recovery rate of implanted ferromagnetic tags per day of sampling (open circles) and for the total cumulative data (closed circles).

considered in the calculation. The population size was estimated from the modified Petersen estimator to be 5 761 096 crabs, with probability better than 0·95 of being accurate within 25 % of the true population size (from Fig. 5 in Robson and Regier, 1964). The number of tags recovered was corrected to 87·6, accounting for a possible tag loss of 3·6 %, as estimated from the double-tags, and for a 1·75 % loss of the tagged leg due to handling, as estimated from sampling 1999 crabs in the commercial catch.

The rate of exploitation (u), defined as the fraction of the total stock caught by the end of the fishing season, was 0·22. The total number of individuals caught was 1 246 641, estimated from the total landed weight of 905 560 kg divided by the average individual weight of 726·4 g. This average individual weight was estimated from the total weight (47 025 kg) of 64 737 crabs examined during the experiment.

Discussion

The tagging equipment used in this experiment proved to be reliable for rapid tagging of large numbers of crabs under field conditions. Nevertheless, as emphasized by Koerner (1977), care was required to ensure that the injector worked properly. One problem encountered during the routine tagging operation in automatic mode was the occasional tendency for tags to stick to the hypodermic needle on retraction from the dactylus. It is possible that a tag thus improperly injected could stick to the outside of the cuticle, and be subsequently magnetized and correctly detected, thus explaining the double-tagged crab recovered without an implanted tag. Another explanation is a possible shedding of the injected tag when the crab was at large. A more careful insertion of the needle before automatic implantation of the tag improved tagging effectiveness and resulted in fewer untagged crabs. Nevertheless, an absence of the implanted tag in 3·6 % of the tagged crabs recaptured was taken into account in estimating stock size.

The main assumptions in the Petersen method do not appear to be seriously violated in our study. Snow crab is not a very mobile animal (Watson, 1970; Watson and Wells, 1972), and recruitment due to moulting was absent during the experiment. The assumption of a closed population is thus reasonable. Effort was made to distribute the tagged crabs among the total population. A delay of one month between tagging and recapture contributed to a further mixing of the tagged crabs in the population. The loss of tags was accounted for, based on results from the double-tagging and on observations on the shedding of legs after capture. A frequent problem with tagging studies is that recaptured animals are

often overlooked by fishermen. This was not the case in our experiment. Finally, the ratio of tagged crabs to number examined fluctuated around a mean of 7·6/10 000 crabs without any noticeable trend (Fig. 4). This is a general indication that the tagged and untagged crabs had a similar probability of being caught.

Although a tagging study of stock size requires more sampling effort with an implanted tag than with external tags, our experiment has shown that it is both feasible and statistically valid. It has yielded an estimate of population size with levels of accuracy and precision generally recommended for management purposes. The significance of the estimate could be improved by increasing the number of crabs tagged, or the number examined for recoveries, or both. For instance, the number of crabs examined could be increased by the use of automated devices such as those tested for fish (Ebel, 1974; Corten, 1980). More efficient techniques would allow this method to be used for much larger stocks.

Further experiments are needed before the method can be fully evaluated for growth studies of *Chionoecetes opilio* in the field. Although our observations in captivity suggest that the tag does not affect the crabs and would be retained during ecdysis, this has not been tested because no crab moulted successfully. Prentice and Rensel (1977) attributed no mortality to the tagging of prawns with the same equipment. As in our experiment, they observed the formation of a black spot at the tagging wound site, but histological examination showed no inflammatory response. Moreover, Tutmark *et al.* (1967) for three species of crabs and Wickins and Beard (1984) for *Homarus gammarus,* observed no negative reactions. Ennis (1972) observed several lobsters (*H. americanus*) which retained an implanted tag through a moult in the field. In captivity, small juvenile lobsters (*H. gammarus*) moulted up to six times with a tag retention of approximately 97 %, although in another trial with a different machine the retention was only 68 % (Wickins and Beard, 1984). It was suggested that the small size of the lobsters (12-mm carapace length), the difficulty of positioning the tag properly, and the possibility that the tag was shed at ecdysis were responsible for the lower retention percentage. In snow crab, current laboratory research suggests that proper implantation of the tag in the dactylus may be critical for good retention during ecdysis (Dr Jeff Hurley, pers. comm.). Crabs tagged just prior to ecdysis have shown adverse reactions to the tag, such as bending of the soft dactylus or autotomy of the tagged leg, but their growth was similar to that of a control group. A further reason to avoid tagging close to a moulting period is to reduce the risks of biasing the results on the moult frequency, as suggested by Hancock and Edwards (1967).

The size-class approach adopted to identify the size at tagging could have been useful in estimating the size increment within the size classes smaller than 95 mm. Unfortunately, only 6·1 % of all tagged crabs were in this category. More crabs of this size were expected in the catch and the initial aim was to measure growth in the pre-recruits. The two size classes above 95 mm were so wide that no useful estimate of size increment could have been obtained. Moulting in the 95–109 mm size class, but not in the larger size class, would only be detected but not measured. Nevertheless, this method could be refined by the use of more and narrower size classes, working with different combinations of pereiopods and a larger number of differently coded spools of ferromagnetic wire. Ultimately, the best system should use individually coded tags.

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