ESCAPE MECHANISMS IN CRAB AND LOBSTER POTS- IMPLICATIONS FOR SNOW CRAB (*Chionoecetes opilio*) STOCK CONSERVATION AND POLICY REVIEW

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By

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Abstract

Since the collapse of groundfish stocks in the early 1990s, market demand and industry diversification has placed considerable pressure upon crab stocks in Newfoundland and Labrador, specifically snow crab (*Chionoecetes opilio*). The total allowable catch (TAC) for snow crab in the Newfoundland region peaked in 1999 at 69,000 tonnes. Fisheries and Oceans Canada has been reactive in its approach to management and has implemented various measures in line with the precautionary approach.

Work conducted on modifications to crab pots, specifically the development of escape mechanisms for undersized crab, has generated attention as a means to improve sustainability of the resource. Commentary from local crab harvesters using experimental escape devices in their pots has been positive in that they are seeing less undersized crab in their catch. This translates to reduced sorting time for the harvester, less mortality, and fewer non-commercial crab exposed to air and drop factors. This further increases the chance that these undersized individuals will be available for harvest in subsequent years.

The use of escape mechanisms in shellfish fisheries is not a new concept. Reducing ghost fishing of lost and derelict gear has prompted research that has translated into new management measures in many jurisdictions. Reducing the incidental capture of undersized crab and lobster has been an additional outcome of escape device utilization is most crab and lobster fisheries around the world.

Experiments were conducted in Newfoundland as early as the 1890s with escape devices in lobster gear. While lath spacing in lobster pots has been enforced since 1937 it is

interesting that the use of rigid escape mechanisms in snow crab pots has not yet been adopted as a mandatory management measure although efforts to recommend policy changes have been underway since 2004 in the region.

The following document reviews the use of escape mechanisms in different decapod fisheries around the world, benefits of their use in Newfoundland and Labrador, and the implications for snow crab stock conservation and policy review.

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List of Abbreviations

BCD - Bitter Crab Disease

CCFI - Canadian Centre for Fisheries Innovation

CPUE - Catch Per Unit Effort

CW - Carapace Width

DFA - Department of Fisheries and Aquaculture (Provincial)

DFO - Department of Fisheries and Oceans (Federal)

FFAW - The Fish, Food and Allied Workers Union

GTR - Galvanic Time Release (Device)

ITQ - Individual Transferable Quota

LFA - Lobster Fishing Area

MI - Fisheries and Marine Institute of Memorial University of Newfoundland

NAFO - Northwest Atlantic Fisheries Organization

NMFS - National Marine Fisheries Service

NPFMC - North Pacific Fishery Management Council

PEIFA - Prince Edward Island Fishermen Association

RAP - Regional Advisory Process

SELECT - Share Each Length's Catch Total

TAC - Total Allowable Catch

1.0 Introduction

The cod fishery moratorium has resulted in considerable change in the modern fishery in Newfoundland and Labrador with a shift in recent years from groundfish to higher valued shellfish species (Gardner Pinfold, 2006), namely snow crab and shrimp. Although snow crab is not a new fishery for the province, the significant harvesting pressure placed on it could impact the long-term sustainability of the resource, particularly with longer-term recruitment prospects in an uncertain state (DFO, 2007a).

Management agencies have come under increasing pressure to ensure sustainable fisheries for future generations. The passage of the Ocean's Act in 1997 marked a significant legislative commitment by the Canadian government to take a comprehensive approach for the protection and development of Canada's oceans and coastal waters. This legislation was followed by action plans, strategies, and policy and operational frameworks developed by the federal Fisheries and Oceans department that called for change in policy direction for the federal government to be more inclusive of the full spectrum of ocean users and the Canadian population at large. Today's ocean resource users include those involved in aquaculture, oil and gas exploration and development, recreational and commercial fishing, and ecotourism. However, the list does not end there. Scientists, environmentalists, Aboriginal people, consumers, the media, banks, and the public at large are also effectively resource users (Mikalsen and Jentoft, 2001), with a stake in the sustainability of the oceans. The challenge becomes managing the demands of resource users while protecting the marine environment and ensuring long-term sustainability of Canada's oceans and its resources (DFO, 2002a; 2002c).

Fisheries throughout the world have been challenged to meet sustainability goals. Bycatch is at the forefront of criticism for many fisheries and, as such, bycatch reduction research is prevalent in the peer-reviewed literature. Research has often led to recommendations that have further led to the adoption of regulations set in place in an effort to reduce the amount of bycatch in particular fisheries (Templeman, 1939; 1958; Wilder, 1949; Jow, 1961; Bowen, 1963; Krouse and Thomas, 1975; Eldridge *et al.*, 1979; Brown and Caputi, 1983; 1985; 1986; Maynard *et al.*, 1987; Everson *et al.*, 1992; Lanteigne *et al.*, 1995).

Research efforts began in the late 1800s to reduce the catch of undersized lobster (*Homarus americanus*) and effectively protect undersized lobster from handling mortality (Templeman, 1958). As other valued resources have been reported as overfished or declining, protecting undersized, non-target animals had led to considerable publications on crab species in more recent years (Breen, 1987; Gendron and Hébert, 1990; Gagnon and Boudreau, 1991; Hébert *et al.*, 1991; Kimker, 1994; Guillory and Prejean, 1997; Guillory, 1998; Guillory and Hein, 1998a; Guillory *et al.*, 2004; Salthaug and Furevik, 2004; Watanabe, 2005).

The snow crab (*Chionoecetes opilio*) fishery in Newfoundland and Labrador is of considerable economic importance to the province. The total allowable catch of snow crab peaked in 1999 but total allowable catches and associated landings have not reached comparable levels since. Stock levels are known to fluctuate both temporally and spatially. In an effort to sustain the resource DFO has implemented several management measures.

This paper will discuss the research, use, and regulations pertaining to escape mechanisms in decapod fisheries throughout the world available in the scientific literature. Escape mechanisms enable fishing gear to be more selective and allow undersized, non-target animals to escape before the gear is hauled. Additionally, this paper will discuss the implications of such devices for snow crab (*Chionoecetes opilio*) stock conservation, sustainability, and policy review in Newfoundland and Labrador.

2.0 History of the Snow crab fishery in Newfoundland and Labrador

The Newfoundland and Labrador snow crab (*Chionoecetes opilio*) fishery began in 1968 in Trinity Bay but was not widespread along the northeast coast (NAFO Divisions 3KL) until 1979. Fisheries began on the south coast of Newfoundland (NAFO Subdivision 3Ps) and off Labrador (NAFO Division 2J) in 1985 and moved offshore on the northeast coast (NAFO Division 3K) during the mid-1980s as well (Dawe *et al.*, 2006; DFO, 2006; 2007a). At this point in time the Alaskan red king crab fishery plummeted greatly (Dew and McConnaughey, 2005; Orensanz *et al.*, 1998) and the growing Japanese market demand created opportunities for other jurisdictions (Louckes, 2007).

The crab fishery continued to expand in Newfoundland and Labrador as a result of market demand and industry diversification (Taylor *et al.*, 1989). Supplementary fisheries, that is, fisheries developed to provide fishers who had been negatively impacted by declining groundfish stocks access to the snow crab resource to supplement incomes, were developed in 3K, 3Ps, and 3L, and 2J. The fishery continued to expand into the offshore and small-scale exploratory fisheries in Bay St. George, Bonne Bay, and Bay of Islands on the west coast of Newfoundland further developed the industry. Significant landings were harvested from NAFO Division 4R starting in 1993 (Dawe *et al.*, 2006; DFO, 2006; 2007a).

For a visual representation of the management areas of the snow crab fishery in Newfoundland and Labrador please refer to Figure 1.1 (below).

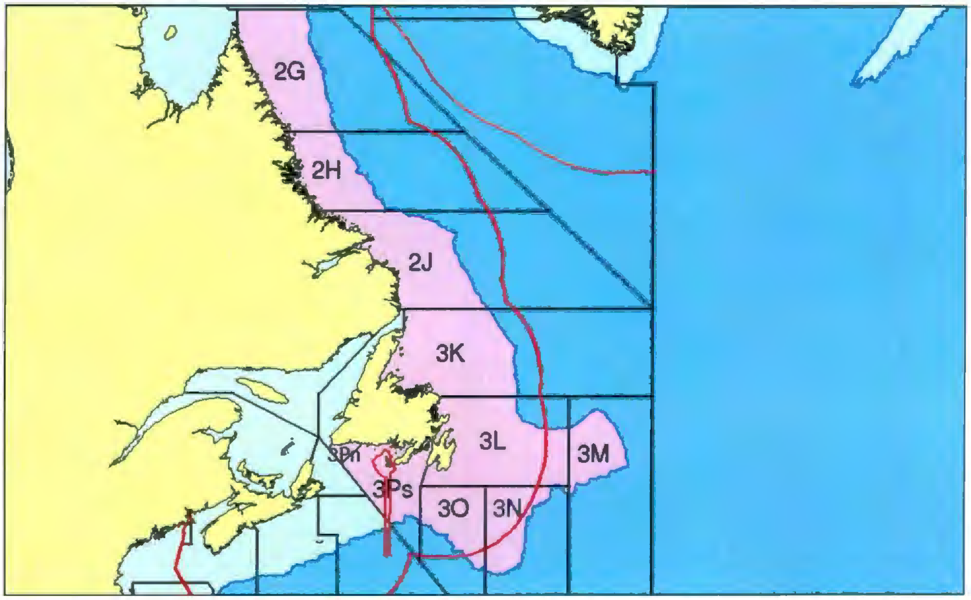

Figure 1.1 Management Areas of the snow crab fishery for the Newfoundland and Labrador Region of DFO (*Source*: DFO, 2007a).

Temporary seasonal snow crab permits were issued for inshore vessels (under 35 feet) in 1995 in response to increasing snow crab resources and the decline of groundfish resources that fishers had traditionally depended. As snow crab quotas increased, temporary seasonal permits were made available to small boat enterprises with participation increasing annually from 1996 to 1998. Temporary seasonal permits were converted to licenses in 2003 if the fisher held a seasonal permit in 2000, 2001, or 2002 (DFO, 2006).

The snow crab resource was initially harvested as gillnet bycatch but has since switched to conical baited traps set in longlines and the fishery has expanded throughout Divisions 2J3KLNOP4R. Landings and commercial catch per unit effort (CPUE) first peaked in

1981 but the resource then declined during the early 1980s. It recovered however and remained high during the 1990s. In fact, 1999 saw peak landings of 69,000 tonnes harvested in the Newfoundland region attributed to expansion of the fishery into offshore areas. Landings decreased by twenty per cent to 55,400 tonnes in 2000 and remained relatively stable until decreasing again another 20 per cent to 43,900 tonnes in 2005. This decrease was primarily due to a decrease in landings in Division 3K where the total allowable catch (TAC) was not taken. Landings increased somewhat in 2006 due to increases in Divisions 3KL (Dawe *et al.*, 2006; DFO, 2006; 2007a). Table 1.1 presents quotas, landings, landed value, and average unit price for snow crab harvested in the Newfoundland and Labrador Region from 1986 to 2005.

Table 1.1 Snow crab quotas, landings, landed value, and unit prices from 1986-2005. (*Source*: DFO, 2006).

Year	Quota (TAC) (,000 t)	Landings (,000 t)	Landed Value ($ million)	Average Price	
				$/tonne	$/pound
1986	9.2	9.0	10.3	1,145	0.52
1987	8.4	6.7	12.6	1,882	0.85
1988	8.6	9.6	21.8	2,271	1.03
1989	10.1	8.3	10.3	1,241	0.56
1990	10.5	11.0	13.1	1,191	0.54
1991	15.8	16.2	19.9	1,228	0.56
1992	14.5	16.4	13.0	793	0.36
1993	18.7	22.9	31.7	1,384	0.63
1994	23.8	27.9	87.2	3,126	1.42
1995	31.9	32.4	176.2	5,438	2.47
1996	37.8	38.0	96.8	2,547	1.16
1997	44.5	45.7	91.7	2,007	0.91
1998	49.2	52.7	102.2	1,939	0.88
1999	61.2	69.1	236.2	3,418	1.55
2000	51.2	55.5	268.0	4,829	2.19
2001	52.3	56.7	218.8	3,859	1.75
2002	57.0	59.5	229.5	3,857	1.75
2003	56.3	58.4	263.6	4,680	2.00
2004	53.6	55.7	300.6	5,608	2.45
2005	50.0	44.0	140.3	2,806	1.45

2.1 Management of Snow Crab Fishery

The snow crab resource in Newfoundland and Labrador is currently managed under a three-year integrated fisheries management plan. The status of the snow crab resource is assessed annually and conservation measures and quota levels are announced annually as well (DFO, 2006).

2.2 Management Tools for Snow Crab

2.2.1 Minimum carapace size limits

The overall management strategy for snow crab is to ensure that the total harvest has little impact on the reproductive potential of the snow crab resource. The minimum carapace (shell) width (CW) for harvesting snow crab in Newfoundland and Labrador is 95 mm. At this legally set size most males have had the opportunity to mate at least during one mating season. Female snow crab do not reach this size and are thus excluded from the capture fishery. Females, undersized males, and uncaught legal sized males are assumed to be sufficient to maintain reproductive potential of the resource (Dawe *et al.*, 2006; DFO, 2006).

2.2.2 Gear Restrictions and Trap Limits

The primary mechanism to regulate the size of captured crab is by regulating the size of the mesh in crab traps. The minimum legal mesh size of the traps is 135 mm, which enables the majority of small crab to escape. Trap limits are also imposed and vary by fleet and area (DFO, 2005; 2006; Dawe *et al.*, 2006).

2.2.3 Harvesting Practices

In recent years significant emphasis has been placed on maintaining the quality of landed snow crab. Trip limits have been set to avoid harvest and processing gluts and observer coverage on vessels and dockside monitoring have become mandatory activities. Education initiatives have been put in place on the proper handling practices for grading and stowing market size crab as well as effective releasing practices for undersized and soft shell snow crab. Shorter fishing seasons and strict protocols to close areas with a high incidence of soft shell crab being harvested have provided additional protection to the resource during moulting when crab are highly vulnerable (DFO, 2006). Soft shell crab also exhibit a lower meat yield than hard shell crab (Taylor *et al.*, 1989).

2.3 Stock Assessment of Snow Crab

A Regional Advisory Process (RAP) meeting for snow crab is held in the spring of each year where Department of Fisheries and Oceans (DFO) scientists and fisheries managers, industry representatives, and external experts review available information on research and commercial data. Two key indicators of stock status are the commercial catch rate and the fall bottom trawl surveys. Data is compared with catch rates from inshore trap surveys, fishery logbooks, observer catch-effort data, and post-season trap surveys (DFO, 2007a).

Research on the performance and use of escape mechanisms in conical snow crab pots under commercial conditions was presented at the RAP meeting held from February 27 – March 2, 2007. Eleven harvesters from six communities along the east and south coast of

Newfoundland used specially designed escape mechanisms in their pots. Results showed that escape mechanisms can act as selectivity devices. Pots that fished with escape mechanisms caught significantly less undersized crab while catching the same amount of legal size crab compared to traditional pots without escape mechanisms installed. Recommendations from the researchers, including participant (harvester) feedback, suggested that escape mechanisms be permitted in crab pots on a voluntary basis (DFO, 2007b).

Although meeting participants considered the preliminary research results to support voluntary implementation of escape mechanisms in the fishery (DFO, 2007b), the use of escape devices in crab pots in Newfoundland and Labrador was still under management consideration for 2007 and 2008. The use of these escape mechanisms increased to 36 harvesters in 25 communities for the 2008 fishery (Keats *et al.*, 2008) and an estimated 136 harvesters were to use escape mechanisms in their pots during the 2009 fishery (Dr. Paul Winger, Centre for Sustainable Aquatic Resources, pers. comm.).

There is agreement that fishery-induced mortality of undersized males (and females) could affect future recruitment. Options to reduce fishery-induced mortality include the use of escape mechanisms and biodegradable panels in pots. Early fishing seasons, increasing mesh size and soak time, as well as improving handling practices and reducing high-grading have also been suggested to reduce fishery-induced mortality (DFO, 2005; 2006).

3.0 Escape Mechanisms

The idea of escape "mechanisms" to regulate the capture of undersized decapods has been around for over a century. For clarification purposes, escape mechanisms in this document's context refer to rigid devices that are incorporated into fishing pots or traps to enable non-targeted animals, including undersized target animals, to escape prior to being harvested, culled, and then returned to the sea.

Escape mechanisms are not to be confused with escape panels, that is, sections of a pot or trap that are either made from a biodegradable material or are attached to the pot or trap with some type of biodegradable material. Over time the biodegradable material of escape panels will degrade and allow the escape of animals from the gear. Escape panels will also be discussed in this paper as they are mandatory in some crab fisheries.

3.1 The mechanics of escape mechanisms

Today, escape mechanisms are used commonly in many decapod fisheries throughout the world. Studies have shown that the rigidity of such a device, coupled with the rigid exoskeleton of the dexterous animal, facilitates undersized animals to escape from the pot through the escape vents or rings. Such a rigid structure enables precise size selectivity of targeted animals (Miller, 1990). In fact, as a generalization, Stasko (1975) noted that rock crab (*Cancer irroratus*) and lobster (*Homarus americanus*) can orient themselves so well that the smallest opening that one can push an animal through by hand is the smallest opening that an animal can orient itself through alone. Escape gaps are therefore designed so that an animal below the legal size limit can escape from the fishing pot but commercial sized animals will be retained.

Of course, in order for an escape mechanism to be effective in allowing undersized animals to escape the animals must locate the escape gap and voluntarily exit (Miller, 1990). One could argue that the success therefore of the use of these escape mechanisms is variable and may be dependent on the nature of the individual animal.

Karnofsky and Price (1989) conducted tank observation studies on lobster (*Homarus americanus*) and suggested that individual lobster have different motivational levels in terms of approach to a trap and subsequent capture. Their experimental set-up included the use of escape vents and, as a result, the traps did not retain any undersized lobster. They reported that small lobster that entered the traps found the escape vents quickly, that is, in less than one minute. In fact, in some instances, they observed small lobster escaping the trap only to immediately re-enter through the trap entrance. They suggested that the presence of the vents may actually increase the long-term capture efficiencies for larger lobster as smaller lobster will be conditioned to enter traps over time (and escape) until they reach a size when they can no longer escape through the vents.

Laboratory observations by Nulk (1978) demonstrated that lobster can turn on their side to escape from a vent. He further noted that some lobster escaped through a vent up to five millimetres smaller than the smallest point of their carapace width.

Preliminary observations by Miller (1980) indicated that, given the opportunity, crab will escape from pots. In fact, he noted that rock crab (*Cancer irroratus*) and spider crab (*Hya araneus*), although with some difficulty, managed to manoeuvre themselves around a sharp 180 degree turn to escape from the top side of a pot entrance. Once he fitted pots with a plastic collar or a one-way door for traps with side entrances all animals captured were retained. While this research didn't directly involve observations of animals towards escape mechanisms it does indicate that rock crab and spider crab are motivated to escape, given the opportunity.

Laboratory and at-sea observations characterized a four stage behavioural process regarding the escape of snow crab (*Chionoecetes opilio*) from rigid, circular escape mechanisms (see Figure 3.1 below). Initially, crab approach the escape hole with the body low while extending three of four hind legs through the opening. The animals then raise and orient their body through the opening and bring the closest claw through the opening as well, either before of after the body proceeds through the opening. Finally, the crab bring the other claw through the escape mechanism and lower themselves to the ground outside the pot with hind limbs from the other side of the body trailing (Winger *et al.*, 2006; Winger and Walsh, 2007).

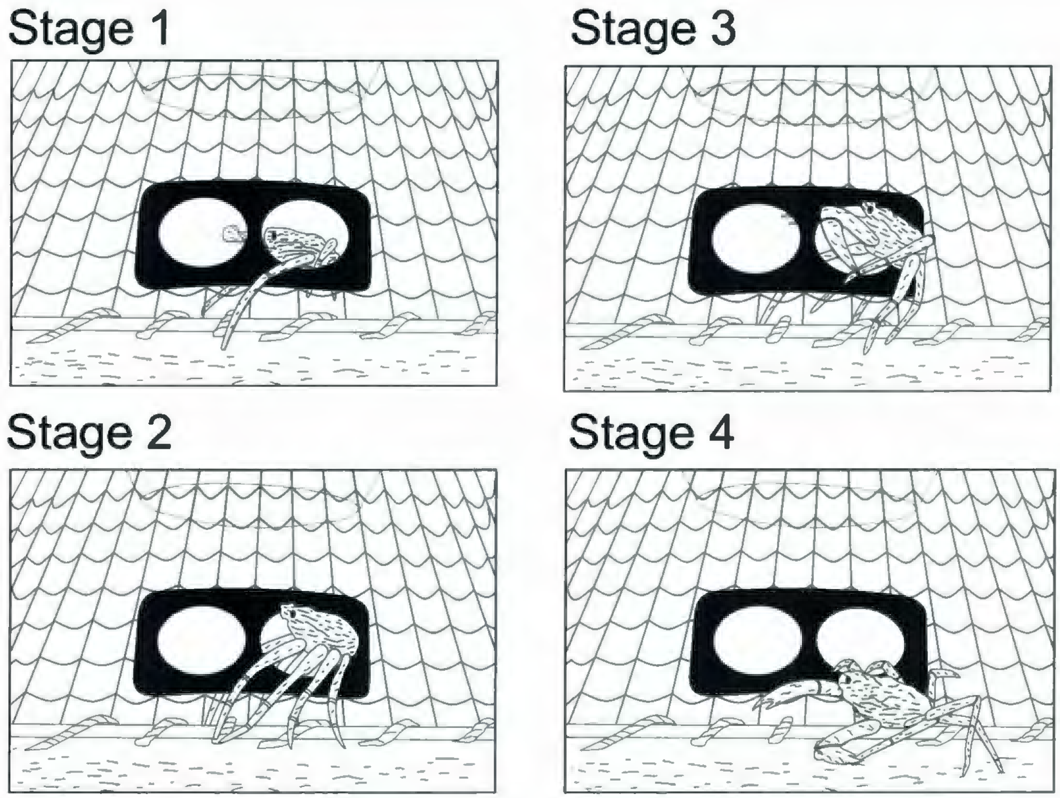

Figure 3.1 Four stage behavioural process of snow crab (*Chionoecetes opilio*) escape from rigid, circular escape mechanisms. (*Source*: Winger and Walsh, 2007).

3.2 The "Evolution" of Escape Mechanisms

Just as the location, shape, and size of the entrance of a trap or pot can be species-specific to effectively "catch" targeted animals, so is the location, shape, and size of an escape mechanism. The material of the escape device as well as the species and region of fishing is also important to consider. There are a variety of different types of escape mechanisms in use today.

3.2.1 Early Lobster Research in Newfoundland

Research on lath spacing as a means of regulating the catch of undersized lobster was conducted in the 1890s in Newfoundland. A Norwegian researcher, Adolph Neilsen, was the Superintendent of Fisheries in Newfoundland from 1889 to 1896. In addition to his work establishing a cod hatchery on Dildo Island, Trinity Bay, he conducted experiments varying the lath spacing of lobster pots. From his experimental work he established the concept of using wider spaces between the lowest laths of each side of the lobster pot to enable undersized lobster to escape (Templeman, 1958). Please refer to Figure 3.2 (below) that depicts wider lath spacing near the bottom of the lobster pot. The oldest type of escape mechanisms were therefore adjustments to the spacing of wooden laths in lobster pots.

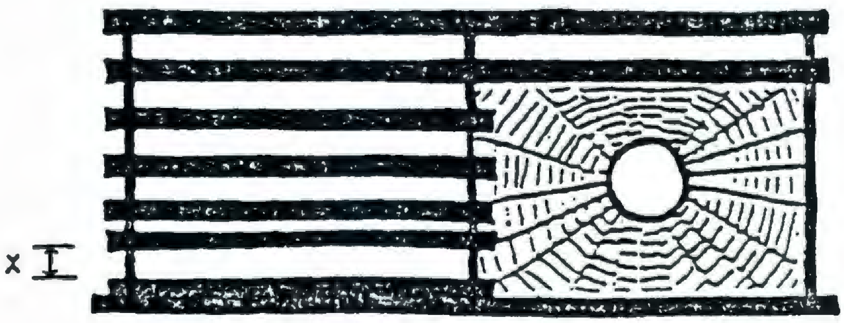

Figure 3.2 Lath spacing of a traditional lobster trap where the wooden lath space, X, in the lower left section of the pot, provides an opening large enough that undersized lobster can escape from the pot while legal-sized animals are retained. (*Source*: Maynard *et al.*, 1987).

Neilsen's research later led to a regulation for the Newfoundland lobster fishery in 1893 requiring 1 ¾ inch (4.4 cm) lath spacing between the two undermost laths on each side of the lobster trap. Many fishermen however were sceptical of this law and the value it brought to the fishery. They suggested that undersized lobster would still be caught, that small lobster and other animals, such as crab, could freely enter and exit the trap and eat the bait, thus affecting the attraction of larger lobster to the pot, and also that legal sized lobster could escape through the 1 ¾ inch (4.4 cm) lath spacing so fewer legal sized lobster, at that time 9 inches (22.9 cm) long and over, would be caught (Templeman, 1939; 1958).

Although Neilsen's research was limited and it was later determined that he had underestimated the size of lobster able to escape from a lath space of given size his work did establish the use of lath spacing in lobster pots. As well, research continued in an effort to protect undersized, non-targeted animals from pot fisheries (Templeman, 1958).

As the minimum size limit for retaining lobster varied in the early twentieth century in Newfoundland so did the regulation regarding the space of the laths. In 1897, for example, the minimum size for lobster was nine (9) inches (22.9 cm) and the lath spacing was regulated at 1 ½ inch (3.8 cm). By 1904 the size limit for lobster was reduced to eight (8) inches (20.3 cm) and laths were required to be not less than 1 ½ inches (3.8 cm) apart. The size limit again changed to cight and one-half (8 ½) inches (21.6 cm) in 1929, nine (9) inches (22.9 cm) in 1935, and just over nine (9) inches in 1942. The spacing between the two undermost laths remained at 1 ½ inches (3.8 cm) until 1933 or later but the 1 ¾ inch (4.4 cm) lath spacing regulation has been enforced in Newfoundland since 1937 (Templeman, 1958; Elner, 1980).

Templeman (1939) conducted research on the west coast of Newfoundland in St. George's Bay in 1938 that supported the 1 ¾ inch (4.4 cm) regulation. His experimental results demonstrated that lobster traps with the 1 ¾ (4.4 cm) lath spacing retained a much smaller number of undersized lobster (twenty per cent less) but the same number of legal lobster in comparison to traps fished with the 1 ¾ inch (4.4 cm) lath spacing closed. Templeman conducted his experiments during warm weather when bait disappears quickly. Yet, the same numbers of legal sized lobster were attracted to the traps with the 1 ¾ inch (4.4 cm) lath spacing as the traps without the lath spacing. The argument that the 1 ¾ inch (4.4 cm) lath spacing will allow other animals to eat the bait therefore does not stand. He further noted the importance of a smaller catch of undersized lobster. Fisherman would be more likely to throw back small lobster when there were fewer of them and fewer undersized lobster would be rough handled to the detriment of their valuable claws.

3.2.2 Early Lobster Research in the Maritimes

Between 1943 and 1946, Wilder (1949) conducted similar lath spacing experiments in many areas of the Maritimes with the help of experienced and successful lobster fishermen under commercial conditions. His results advocated for spacing trap laths not closer than 1 ¼ inch (4.4 cm) apart. Wilder further promoted the idea by advising of the additional advantages of wide-spaced traps, aside from the escape of undersized lobster.

He reported that bycatch of other species would be reduced and fewer lobster would be injured by jamming their claws between the laths. This would make the culling process more efficient. Additionally, new traps built with wider lath spacing would require fewer laths, less ballast, and would be lighter and easier to haul. Finally, old traps could be modified by widening only the lowest laths on the sides (Wilder, 1949). Subsequently, a law was passed in 1949 affecting fishers in the Gulf of St. Lawrence that required lobster caught for canning to be fished in traps with 1 ¼ inch (3.2 cm) lath spacing and lobster destined for the live export market to be fished with traps requiring 1 5/8 inch (4.1 cm) spacing between the laths (Templeman, 1958).

Fisherman complained about the effort involved in modifying large numbers of pots. They also believed that lobster were damaging their legs and chelipeds with the wider lath spaces which represented a financial loss to the harvesters when they went to sell their catch. They further alleged that bait disappeared more quickly with wider lath spacing and legal sized lobster escaped through the lath spacing. Finally, the laths could be chewed and worn increasing the size of the spacing and thus allowing additional legal-sized animals to escape. Although the lath spacing regulations for the Maritimes and Quebec were rescinded in 1955, Templeman (1958) continued to advocate for the revoked regulation and challenged every argument and belief put forward.

Direction for Canadian lobster management research subsequently shifted and investigated escape vent panels which were less controversial, but viable, alternates to lath spacing. Lewis (1978) conducted field trials with lobster pots fitted with a wooden panel containing three circular escape vents of 45 millimetres in diameter. He also compared plastic escape vents under similar circumstances. Although he noted no significant difference in the number of undersized lobster that escaped, there was a trend indicating that legal-sized lobster preferred the wooden panels. Lewis' results were communicated to Prince Edward Island lobster fisherman to encourage the use of escape panels in their pots.

3.2.3 Lobster Research in Australia and New Zealand

Early research in Australia and New Zealand documented lath spacing work as well. Bowen (1963), from his research in Western Australia, determined that the size selectively of crayfish (*Panulirus cygnus*) pots was largely dependent on the lath spacing in the pots. Ritchie (1966) considered the total area of the escape vent panel in determining its effectiveness for crayfish escape in New Zealand. Winstanley (1971) conducted a statistical evaluation on the relationship between carapace length and height of the southern rock lobster (*Jasus novaehollandiae*) in Tasmania.

While all Western Australian rock lobster (*Panulirus cygnus*) pots required a 54 x 305 millimetre escape mechanism as per regulation (Bowen, 1963), Brown and Caputi (1983; 1985; 1986) still advocated to increase the size of the regulated escape gaps as an estimated 16 to 20 million undersized rock lobster were caught, handled, and released each season. Experimental work with three widths of escape gaps (54 mm, 55 mm, and 56 mm) and one and two escape gaps in pots showed a significant trend such that as the escape gap size and number increased, the percentage of undersized lobster retained decreased while the percentage of legal-sized animals remained relatively constant. Additionally, the authors advocated for minimal exposure and displacement of undersized animals that are harvested suggesting further education and publicity was needed (Brown and Caputi, 1983; 1985; 1986).

Chittleborough (1974) noted in his study on homing range of juvenile western rock lobster (*Panulirus longipes cygnus*) on Australian reefs that both escape mechanisms in pots and encouraging fishermen to return undersized lobster to the reef of capture is important from a fisheries management perspective. As Brown and Caputi (1983) noted, displacement makes lobster more vulnerable to predation, which has implications on the future of the stock.

Work by Brock *et al.* (2006) also shows that pots fitted with escape mechanisms do not impact predation rates of southern rock lobster (*Jasus edwardsii*) by octopus. Furthermore, the pots equipped with escape mechanisms retained less undersized lobster. The presence of escape mechanisms may therefore help in controlling octopus predation, a significant problem in some areas, while reducing mortality of undersized lobster. This recent work is noteworthy as the South Australian Rock Lobster Fishery does not require mandatory escape mechanisms. The authors encouraged the use of the escape devices while noting their use in the southern zone of the fishing area would decrease the number of undersized lobster killed by octopus by about 50 per cent per year. Work conducted by

Ritchie (1972) demonstrated similar effectiveness of escape gaps to reduce predation on rock lobster (*Jasus edwardsii* and *Jasus verreauxi*) by octopus in New Zealand. Escape gaps in this fishery have been in effect since 1970.

3.2.4 Lobster Research in New England

Coinciding with the time period in which Adolph Neilsen was experimenting and conceptualizing the use of lath spacing to reduce the catch of undersized lobster a convention was held in Boston, Massachusetts in September 1903 to secure better protection of the lobster resource in American waters. Delegates from the Dominion of Canada and Newfoundland were also invited to the meeting to consider options and uniform regulations to prevent the "commercial extinction" of the lobster. At this meeting Captain Robert E. Conwell of Provincetown, Massachusetts presented to the convention that the fishers involved with the Provincetown lobster fishery put the slats in their traps 2 inches (5.1 cm) to 2 ¼ inches (5.7 cm) apart. As a result, fishermen claimed they did not catch any undersized lobster. Prior to this, Dr. Field of Sharon, Massachusetts stated confidently that a lobster pot could be developed that would automatically regulate the size of lobster caught in traps by preventing the entrance of large adults and allowing undersized lobster to escape. He advised that such a trap would help with the enforcement issue at the time, that is, only lobster between 9 and 11 inches (22.9 and 27.9 cm) could be retained. Law enforcers needed only to examine lobster pots to ensure they adhered to prescribed dimensions and penalize fishers possessing illegal pots (Collins, 1904). Clearly, individuals at the turn of the twentieth century were ahead of their time in terms of published research which materialized in the 1970s as discussed below.

To reduce the culling of excessive numbers of undersized lobster observed by Krouse and Thomas (1975) in the commercial fishery in Maine, investigations were conducted that supported the 1 ¾ lath spacing recommendation of Canadian researchers. At the time of their study, raising the minimum legal carapace size of lobster was being considered. Thus, they recommended if the minimum legal carapace size was increased, escape vent size should change accordingly. However, they advocated for the use of an escape vent made of a durable material and manufactured to appropriate specifications (see Figure 3.3. below). The escape vent could therefore be easily incorporated into any conventional lobster trap, new or old, at minimal cost to the harvester. An escape vent made of a durable material, such as plastic, would also retain its original dimensions and not wear over time and thus create a larger opening for legal sized lobster to potentially escape. Krouse and Thomas (1975) further supported the use of escape vents as a conservation measure to reduce culling of undersized lobster, reduce sorting time by fisherman, reduce the illegal sale of undersized lobster, and also reduce the number of lobster potentially retained in lost traps.

As the benefits of escape mechanisms became recognized, research efforts expanded to develop more precise devices and designs. The escape panel that became a regulation of the Maine lobster fishery, for example, prompted the development of a research program into plastic escape panels by A. Campbell at St. Andrews, New Brunswick (Elner, 1980).

In addition to studying the behaviour of lobster (*Homarus americanus*) with respect to escape vents, Nulk (1978) took the research a little further by developing a method to recommend the appropriate sized vent or lath spacing depending on the legal capture size of the animal relating carapace length and width. That is, if the legal size of a lobster increased fisheries managers would not need to conduct additional experiments to determine the appropriate size escape mechanism that should be used. Nulk's results were similar to Bowen's (1963) work with crayfish (*Panulirus cygnus*) in Western Australia and Winstanley's (1971) work with southern rock lobster (*Jasus novaehollandiae*) in Tasmania in that a relationship exists between carapace length and width that can predict escapement from vented pots. The method developed by Nulk (1978) could realize a cost savings of research programs designed to determine the optimum escape vent size for various fisheries for future use.

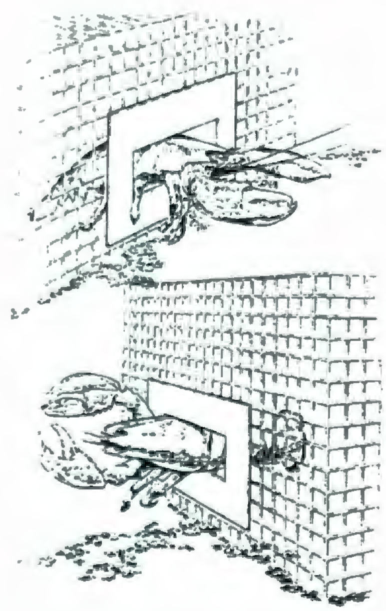

Figure 3.3 Escape of lobster (*Homarus americanus*) through a plastic rectangular escape mechanism observed under laboratory conditions. (*Source*: Nulk, 1978).

3.2.5 Orientation of escape mechanisms

Fogarty and Borden (1980) studied the effect of escape vent orientation (horizontal versus vertical) in pots for the inshore Rhode Island lobster (*Homarus americanus*) fishery as did Krouse (1978) for the Maine fishery. Fogarty and Borden's (1980) study noted that the orientation of the rectangular escape mechanism, that is, horizontal versus vertical, was negligible on the undersized catch. Fogarty and Borden (1980) had postulated that orientation may impact the probability of the animal locating the vent or the time required for the animal to escape. They thought this would be more of a concern with short immersion times of pots however.

Krouse (1978) reported that fewer large crab (*C. irroratus*) were trapped in pots with horizontal vents and CPUE values were lower compared to pots with circular vents, vertically oriented rectangular vents, and nonvented pots.

Maynard *et al*. (1987) took Bowen's (1963), Winstanley's (1971), and Nulk's (1978) work a little further in the southern Gulf of St. Lawrence. They first investigated the efficiencies of three escape mechanisms proposed by fisheries management for the lobster fishery. They tested four types of scenarios (plastic rectangular lath, wooden lath with three circular holes, and two wooden lath space openings) and found that each type of escape device had its own merits. However, the plastic escape mechanism, only one millimetre in size difference from one of the wooden lath openings, was determined to be the most effective in enabling the most undersized animals to escape. The lath with three circular holes retained the most legal sized lobster but also retained the most undersized sized animals.

Due to the variation in lobster carapace size frequency distribution from area to area in the southern Gulf of St. Lawrence, the researchers remarked on the predicament of fisheries management regarding varying points of view. They noted that for any proposed escape mechanism being tested, industry is concerned about the proportion of commercial sized lobster escaping, while biologists are interested in knowing the proportion of undersized lobster escaping. Fisheries managers need to know both pieces of information. For that reason they developed a selectivity prediction model. Management would then be able to select the size of the escape mechanism that would enable the maximum proportion of undersized animals to escape without affecting the proportion of legal sized lobster retained. As mentioned by Nulk (1978), the model offers a low cost alternative to repetitive field trials. Maynard *et al.* (1987) further reiterated that if the legal carapace size for the fishery changes then the escape vent opening size should follow suit.

The work of Maynard *et al.* (1987) led to a regulation in the same year that all lobster pots in the southern Gulf of St. Lawrence be fitted with an escape mechanism to enable undersized animals to escape. Fishers had some choice on the type of escape mechanism employed depending on their Lobster Fishing Area (refer to Table 3.1) as a result of the varying legal minimal carapace sizes in the different areas. All escape mechanisms needed to be positioned 76 mm or less from the floor of the trap (Lanteigne *et al.*, 1995).

Table 3.1 Regulations on minimum carapace size and escape mechanism (shapes and dimensions) in each Lobster Fishing Area of the southern Gulf of St. Lawrence. (*Source*: Lanteigne *et al.*, 1995).

Lobster Fishing Area	Minimum carapace size at capture (mm)	Diameter of openings, circular mechanism* (mm)	Height and width of openings, rectangular mechanism (mm)
23, 25	66.7	44.45	38.1 (H) x 127 (W)
24	63.5	44.45	38.1 (H) x 127 (W)
26A	65.1	44.45	38.1 (H) x 127 (W)
26B, 27	70.0	50.8	38.1 (H) x 127 (W)

*a minimum of two circular openings per trap are required

Fishers in Prince Edward Island thought the 1987 regulation was too compliant which prompted a joint study between the Prince Edward Island Fishermen Association (PEIFA) and the Department of Fisheries and Oceans (DFO) in 1995. The selectivity of the 44.45 mm circular escape mechanisms and the 38.1 x 127 mm rectangular escape vents required in LFA 24 were compared in a commercial lobster fishing situation. Results showed that fewer undersized animals were retained in pots equipped with the rectangular escape mechanisms (Lanteigne *et al.*, 1995). Although the studies by Lanteigne *et al.* (1995) and Maynard *et al.* (1987) both noted some reduction in the capture of commercial sized lobster (canner size category) it was generally felt that this would be temporary as lobster that escape would grow larger and be captured in subsequent years when they reach commercial size.

3.2.6 Lobster and crab research

The development of potential new fisheries for rock crab (*Cancer irroratus*) and Jonah crab (*Cancer borealis*) raised concern that harvesters would capture and impact valuable lobster (*Homarus americanus*) as bycatch. As a result, research was conducted, and interestingly, the use of various types of escape mechanism were studied.

Stasko (1975) investigated several types of traps for use in a potential fishery for rock crab (*Cancer irroratus*) in New Brunswick. The fishery, which was to be held during the closed season for lobster (*Homarus americanus*), required a trap that would prevent the capture of lobster. In laboratory tests, rock crab were observed to walk sideways through available openings making their body depth the limiting factor for escape in rectangular openings. As they passed through round and square openings (sideways) their overall body length became the limiting factor to escape. Lobster, however, generally walked through the various openings head first. From these tests it was found that a round opening would be more selective than a square one to retain commercial sized rock crab while allowing lobster to escape. In field tests, the effectiveness of escape mechanisms could not be assessed unfortunately as the modified traps did not catch any lobster.

Escape vent shape was also explored by Krouse (1978). He noted that *Cancer* crab are often caught as lobster bycatch and some fishers may wish to capture both crab and lobster or be selective for either. Therefore, he examined the efficiency of both circular and rectangular escape vents for retaining commercial sized rock crab (*Cancer irroratus*), Jonah crab (*Cancer borealis*), and lobster (*Homarus americanus*). Results from his work led to the recommendation that all lobster and crab traps in Maine should have a rectangular escape vent or two circular escape vents. To select for market-sized lobster he suggested that escape vents should be positioned next to the sill on the side or end of the trap's parlour section. Fishers selecting for lobster while minimizing crab catches should employ rectangular escape mechanisms. Fishers interested in both lobster and crab, or only crab should use circular vents in their pots. Krouse also recommended the use of synthetic, prefabricated vents recommended by Krouse and Thomas (1975), discussed above, and Fogarty and Borden (1980).

3.2.7 Research with escape mechanisms in crab fisheries

While research to avoid the target of undersized lobster appears to have dominated the literature, Jow (1961) published work on mechanisms tested that enabled undersized Dungeness crab (*Cancer magister*) to escape from pots. Experiments conducted between 1955-1959 with various sizes of circular and rectangular escape vents recommended the use of two 4 ¼ inch (10.8 cm) or 4 ½ inch (11.4 cm) diameter circular escape ports to allow non-marketable crab to escape without reducing the number of legal sized animals in the catch (see escape port in Figure 3.4 below). Concurrent with volunteer efforts by fishermen and research work, the state of California mandated the use of one 4 inch (10.2 cm) escape port in all crab traps in 1957 although, as discussed later, the legislation changed in 1978 to require the use of two escape ports of 4 ¼ inch (10.8 cm) diameter in each pot (Dahlstrom and Wild, 1983).

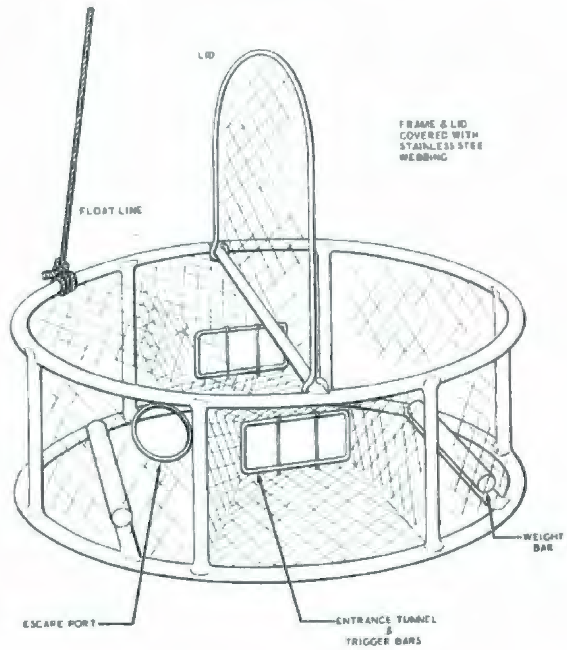

Figure 3.4 A typical pot used in the Dungeness crab (*Cancer magister*) fishery. (*Source*: Jow, 1961).

Early work to develop a self-culling pot to reduce the catch of undersized blue crab (*Callinectes sapidus*) was undertaken by Eldridge *et al.* (1979) in South Carolina. The bycatch of undersized crab was estimated to be upwards of 40 to 50 per cent. While earlier studies investigated the use of larger mesh panels, larger all-over mesh, and escape rings the recommendations resulting from experimentation did not lead to regulations to reduce the number of undersized crab caught in the fishery.

The authors proposed several critical elements necessary in the development of a self-culling pot. They advised that a self-culling pot would need to substantially reduce the amount of undersized crab caught without impacting the catch of legal animals and could not involve great expense or labour on the part of the harvester. Therefore, the researchers tested circular and rectangular escape ports as well as the best size and placement of the escape openings in the crab pot. They found the use of three 2 ½ inch (6.4 cm) inside diameter escape ports to be effective in reducing undersized catch by 82 per cent while maintaining the same amount of legal sized crab (see Figure 3.5 below). They suggested that two ports be located in the top chamber of the pot while the other escape mechanism should be in the bottom chamber of the pot. Using two escape ports, that is, one in the upper chamber and one in the bottom chamber, reduced the catch of undersized crab by 67 per cent. Overall, they stated that the greatest impact with respect to the use of escape mechanisms would be when less conscientious harvesters utilize them in their pots (Eldridge *et al.*, 1979). Interestingly, this state still does not require the use of escape mechanisms in blue crab pots.

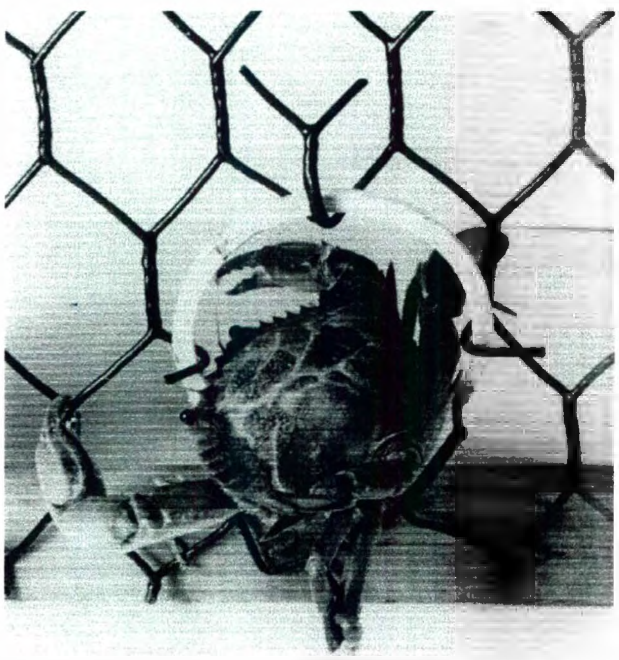

Figure 3.5 An undersized blue crab (*Callinectes sapidus*) escaping from an escape mechanism in an experimental pot. (*Source*: Eldridge *et al.*, 1979).

Vincent Guillory has published extensively in the area of blue crab trap selectivity and ghost fishing either alone or with others. The excessive capture of undersized blue crab has prompted research studies since the late 1970s (e.g. Eldridge *et al.*, 1979) but research efforts heightened in the 1990s when bycatch issues were at the top of fisheries management agendas in the United States.

Guillory and Prejean (1997) noted that while much research has been conducted on blue crab trap efficiency the studies have not considered mesh size and shape as a means of maximizing legal catch and minimizing undersized catch. Experiments conducted with various sizes of square and rectangular mesh and hexagonal mesh demonstrated that a blue crab trap fitted with 38.1 millimetre hexagonal mesh was the most effective trap to maximize legal catch and minimize undersized catch. This was of concern as crab harvesters were adopting traps constructed of 38.1 millimetre square mesh wire which were preferred for their sturdiness and durability over the longer term, but they also catch more undersized crab.

Management measures to contend with increasing effort, competition and conflict, wasteful or damaging fishing practices, habitat degradation, and insufficient assessment information for the blue crab fishery in North Carolina are discussed by Henry and McKenna (1998). Escape rings have been mandatory since 1989 as a measure to reduce the harvest of undersized crab in that state. Gear types and modifications have been investigated to reduce the bycatch of blue crab in the shrimp trawl fishery although more work is needed. Additional study of biodegradable panels and escape mechanisms has been suggested to deal with concerns regarding ghost fishing.

Guillory (1998) further studied optimum mesh size selection in blue crab pots to account for the over ten per cent catch of undersized animals still being retained, even with the presence of escape mechanisms in the gear. He suggested that a mesh size of 44.4 millimetres square was superior to the other sizes tested in that the mesh size had the lowest retention rates of undersized blue crab while still retaining high numbers of legal crab. He further postulated that an optimum mesh size could complement or even replace the use of escape vents for reducing the catch of undersized animals.

While Guillory and Hein (1998a) reported that an escape ring size of 5.87 centimetres in diameter did reduce the catch of undersized crab to 28 to 33 per cent of the catch they still determined this to be excessive. Further pursuing the work discussed above by Guillory and Prejean (1997) they advocated for use of the hexagonal mesh with 6.03 centimetre escape rings to reduce undersized catch of blue crab. Field studies conducted by Guillory (1989) on square (5.08 cm) and circular (6.03 cm diameter) escape vents recommended the use of three escape vents in a pot. This work also stated that square vents were more economical and easier to construct than of the circular PVC vents used in the study although both square and circular escape vents performed equally well during field trials.

In Guillory and Hein's (1998b) review of the literature and escape mechanism evaluation, they reported that an escape ring of 6.03 centimetres (diameter) would be optimal for the blue crab fishery and enable some escapement of small, legal-sized crab. They further suggested that if state regulations do not require the use of escape rings in crab pots, commercial fishers should be encouraged to use them voluntarily.

Guillory *et al.* (2004) directly studied the selectivity efficiency of the 5.87 centimetre and 6.03 centimetre escape rings by comparing the catch of undersized and legal sized blue crab per unit effort in traps fitted with the escape mechanisms. Again, the larger ring size was recommended in order to minimize the capture of undersized crab. In fact, they stated that the use of escape rings of the appropriate size, number, and location can reduce the capture of undersized crab by 75 to 80 per cent.

Gendron and Hébert (1991) conducted similar work to Fogarty and Borden (1980) in Baie des Chaleurs, Quebec, field testing seven different types of traps. Although the recommended conical trap that maximized catch of rock crab (*Cancer irroratus*) did capture some lobster it was felt that the placement of a sufficient number of escape mechanisms of the appropriate size would minimize the number of lobster effectively harvested.

An investigation of escape mechanisms for the Norwegian red king crab (*Paralithodes camtschaticus*) was conducted by Salthaug and Furevik (2004). Results were similar to other studies in that pots fitted with circular escape openings with a diameter greater than 160 millimetres saw a reduced catch of undersized animals. The authors also noted that undersized males had a higher escape rate than small female crab.

Generally, rectangular escape mechanisms are commonly used to retain legal lobster while permitting escapement of many crab and fish species while circular escape devices are used to retain both lobster and targeted crab and fish species (Fogarty, 1996; Miller, 1995). However, Everson *et al.* (1992) found that a circular vent was more effective for spiny lobster (*Panulirus marginatus*) and slipper lobster (*Scyllarides* spp.) in the Northwestern Hawaiian Islands. This work recommended that lobster pots be equipped with two escape mechanisms. Brown and Caputi (1986) also suggested the use of more than one escape gap to reduce the catch and potential mortality of undersized western rock lobster. Several authors have suggested that the dimensions of the escape vent should be slightly larger than the minimum size that retains legal animals but allows for some minimal escapement of legal sized animals lobster in order to ensure maximize escapement of undersized animals (Fogarty and Borden, 1980; Brown, 1982; Guillory and Hein, 1998b). It is important to note however that the use and applicability of an escape mechanism is species-dependent and the size of the device is dependent on the legal size of the animal a fishery is targeting (see Figure 3.6 below).

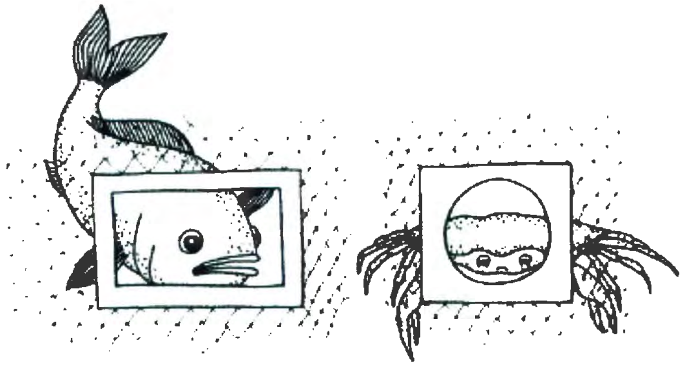

Figure 3.6 The entrance size and shape of an escape mechanism cam be used to select for the animal to be captured and excluded from capture. (*Source*: Miller, 1995).

4.0 Benefits of Escape Mechanisms

So, why would one use an escape mechanism? Ultimately, the use of escape mechanisms protects undersized, non-targeted animals for future years of the fishery, effectively creating a more sustainable fishery for years to come.

Providing an escape opportunity for undersized and non-target animals reduces the number of undersized animals caught and subsequently stressed and/or injured by trap confinement, handling during onboard culling, including air and temperature exposure at the surface, and subsequent discard. While undersized and non-target animals may be returned to the sea with no noticeable signs of imminent mortality, the stress, injury, and/or exposure during the harvest and culling experience may result in reduced growth of the animal, reduced reproductive potential, and increased susceptibility to disease, predation, or starvation. Any of these factors could result in delayed or eventual mortality of the animal, also known as discard mortality (Templeman, 1958; Bowen, 1963; Krouse and Thomas, 1975; Fogarty and Borden, 1980; Guillory and Prejean, 1997; Eldridge *et al.,* 1979; Grant, 2003). On-board handling and discarding could also lead to limb loss which can also reduce reproductive performance (Sainte-Marie *et al*., 1999) and impact stock recruitment as well as reducing commercial value.

With a reduced number of undersized animals in each pot fishing efficiency would increase as sorting time of harvesters would be reduced (Templeman, 1958: Krouse and Thomas, 1975; Eldridge *et al.,* 1979; Fogarty and Borden, 1980; Brown, 1982; Brown and Caputi, 1986; Acrement and Guillory, 1993; Guillory and Prejean, 1997) and undersized animals would be handled quicker, resulting in reduced exposure time (Brown and Caputi, 1986).

The quality of the catch may increase as fewer animals in the pots would reduce the number of conspecific-inflicted injuries such as claw loss (Templeman, 1958; Pecci *et al.*, 1978).

Some studies have documented that the use of escape mechanisms in pots to reduce undersized catch has further increased the catch of legal sized animals (Pecci *et al.*, 1978; Fogarty and Borden, 1980; Brown, 1982; Acrement and Guillory, 1993) and therefore pot efficiency. Work by Treble *et al.* (1998) however did not support the findings of these previous studies.

In other decapod fisheries the sale of undersized animals has been problematic to enforcement personnel. Personnel in the field are not able to catch all those engaged in illegal activity. Undersized animals are also not profitable for processors (Eldridge *et al.*, 1979; Acrement and Guillory, 1993; Guillory and Prejean, 1997; Guillory and Hein, 1998b). Reducing the number of undersized animals captured would lessen the temptation of fishers to harvest and subsequently sell undersized animals (Templeman, 1958; Krouse and Thomas, 1975; Smolowitz, 1978a; Lyons, 1986).

As previously stated, one of the benefits of using escape mechanisms is to reduce the capture of non-target animals. Weber and Briggs (1983) investigated the impact of equipping lobster (*Homarus americanus*) pots with escape vents in the black sea bass (*Centropristis striata*) fishery off the south shore of Long Island, New York. Although their results did not show a difference in catch rates of black sea bass in vented and unvented lobster pots they did conclude that the use of escape vents in the lobster fishery does not constitute any economic loss for the black sea bass fishery. This is significant as incidental bycatch is usually dead by the time it is returned to the water (Saila, 1983). One valuable fishery seeming to significantly impact another valuable fishery could lead to conflicts and reduced stock sizes in one, or both fisheries. Therefore, mitigation of impacts, such as the use of escape mechanisms to prevent the capture of non-targeted animals, would benefit both fisheries in the longer term.

Escape devices are cheaper than re-meshing old pots with larger mesh, if and when regulations change, or when the mesh wears out. Crab harvesters may re-mesh crab pots two to three times as size distribution changes for optimal exploitation of the resource (Dr. Paul Winger, Centre for Sustainable Aquatic Resources, pers. comm.).

Escape mechanisms, if sewn into pots with biodegradable twine or attached with corrodible devices can also be used to reduce ghost fishing if pots should become lost. Smolowitz (1978b) suggested that escape mechanisms may reduce ghost fishing and trap related injuries and mortality due to the decreased catch of undersized animals in lost pots. The issue of ghost fishing will be addressed separately in the next section as the published literature on the subject matter is extensive.

Incorporating escape mechanisms in crab pots also offers opportunities to the industry in terms of market based incentives. The heavy exploitation rate on world fisheries has encouraged the development of various mechanisms to ensure the sustainability of stocks. Ecolabeling is one such mechanism that works to influence consumers and buyers to purchase seafood harvested or produced in a sustainable fashion. This works to the benefit of the fishing industry such that a higher price can be paid for product that has been harvested using responsible and/or sustainable fishing practices. Although it is difficult to determine if ecolabeling schemes have had any impact on sustainability of fish stocks thus far, the certification process itself enables the industry to be reflective of its practices and adopt more environmentally friendly fishing methods that support conservation policies (Washington, 2008).

Incorporating escape mechanisms in pots in the Newfoundland and Labrador snow crab (*Chionoecetes opilio*) fishery would be a strategy that the industry could take in an effort to adopt more sustainable fishing practices. In that regard, installing escape mechanisms in pots would provide the opportunity to undersized crab to voluntarily escape from crab pots before harvest instead of being subjected to harvesting and discarding related injury and/or mortality. This would have longer term impacts on stock recruitment and conservation.

5.0 Ghost Fishing

Ghost fishing has received much attention in the literature on trap fisheries. When traps or pots are lost or abandoned they do effectively continue to capture and retain the targeted species and potentially other non-targeted species as well. For this reason, much research has been done to confirm and assess the problem.

There are two phases of ghost fishing. Initially, bait attracts a high volume of animals. However, once the bait is gone, the pot continues to "fish" and captured animals remain in the pot until the trap is recovered, broken up, or degrades such that animals can escape (Miller, 1990).

Acrement and Guillory (1993) explain that ghost fishing occurs in three phases for blue crab (*Callinectes sapidus*) such that the first stage, as Miller (1990) describes, involves a short period of high recruitment, escape, and mortality due to the attractiveness of the bait. They note the second phase as being transitional in that recruitment declines but mortality increases due to the presence of crab in the pot from the captured in the first phase. The third phase then is the longest phase of continued declining recruitment and lower mortality which serves to attract or rebait other blue crab to the pot.

Guillory (1993), in his research on ghost fishing of blue crab, suggested that mortality of the species in a lost pot would attract others due to the species' cannibalistic nature. Studies conducted on other species such as spider crab (*Libinia spp.*) (Richards and

Cobb, 1987), western rock lobster (*Panulirus cygnus*) (Morgan, 1974), and snow crab (*Chionoecetes opilio*) (Miller, 1977) however exhibited the opposite behaviour, in that conspecifics act as a deterrent to others approaching a pot. Prior conditioning to entering traps, as suggested by Smolowitz (1978b) and Karnofsky and Price (1989), premoult females attracting males to traps, and premoult blue crab (Guillory, 1993), and lobster (Karnofsky and Price, 1989) seeking shelter were also proposed as reasons blue crab (*Callinectes sapidus*) would enter unbaited (lost) pots (Guillory, 1993).

Miller (1977) reported that crab that die in lost traps do not act as bait and therefore do not attract additional crab. In fact, experimental results indicated that the presence of dead crab in pots actually repelled other crab from entering pots.

Research conducted by Richards and Cobb (1987) further supported this apparent alarm response that seems to reduce the catch of conspecifics. To avoid the bycatch of spider crab (*Libinia spp.*) in traps targeting American lobster (*Homarus americanus*) they added freshly crushed *L. emarginata* to the bait bags. The catch of spider crab was significantly reduced when crushed *L. emarginata* was added to the bait. However, the catch of lobster, Jonah crab (*Cancer borealis*), and rock crab (*Cancer irroratus*) was not impacted by the addition of the crushed spider crab in the bait in comparison with experimental pots.

High (1976) conducted experiments to determine if Dungeness crab (*Cancer magister*) could escape from lost pots in Washington. While different escape rates were observed for undersized males, females, and legal males, his results led to the conclusion that crab will escape given an appropriate sized opening such as an escape ring or entrance tunnel (if the triggers are raised or inoperative). The author, however, still questioned the frequency of crab entering unbaited lost pots and effectively becoming trapped.

Pecci *et al.* (1978) conducted a series of experiments in Maine and Massachusetts to assess the effectiveness of escape vents in lobster pots while also observing pot-related mortality due to ghost fishing of "lost" pots. They determined that selectivity of lobster pots can be improved by using escape mechanisms. While the vented pots caught fewer lobster, the pots equipped with escape mechanisms caught larger lobster than pots without escape vents. It was thought that the vents enabled undersized lobster to escape from the pots and thereby reduce injuries and mortality induced by entrapment. Their work also confirmed that "lost" pots do continue to fish; over the study time 25 per cent of the lobster entrapped in the "lost" pots died. "Lost" pots with escape vents or lath spacing of 45 millimetres however demonstrated that mortality can be reduced with their use.

In terms of early research, most studies on ghost fishing have focused on identifying the factors that actually affect ghost fishing. These factors include the number of pots lost, the pot type, size, shape, head design, the location where the pot was lost, and the target species' behaviour (Smolowitz, 1978a; 1978b). However, as ghost fishing has become recognized as a conservation issue and an economic loss to the industry, more recent work has concentrated on preventing and decreasing ghost fishing.

While it would be desirable to believe that all harvesters are conservation-minded and have concerns regarding ghost fishing it is the direct economic cost of lost gear that is important to the majority. With modern gear becoming more durable, easier to handle, and highly efficient in terms of catch rates it becomes the challenge to modify or redesign gear to reduce ghost fishing but still maintain the efficiencies associated with operations.

A move forward in this respect was the suggestion by Smolowitz (1978a) to design a pot that retains only legal-sized animals. In his review he recognized that escape vents were not a new idea and described the early work in Newfoundland and Canada, as discussed above, as well as the work completed in Western Australia and Tasmania with the rock lobster (*P. cyanus*) fishery. He also linked recommendations from research conducted in 1975 by the State-Federal Lobster Management Program and by Krouse and Thomas (1975) that led to the regulation in Massachusetts and Maine requiring escape vents in all lobster pots.

Although Smolowitz (1978a; 1978b) noted that escape mechanisms may reduce ghost fishing mortality of undersized target animals, he also noted that non-degradable pots should contain a section that would degrade over time. Realizing that fishers may find replacing this section cumbersome, he also suggested the concept of a "catch-escape vent" that would be kept shut by a degradable mechanism. Over time the mechanism would degrade and the vent would open if the pot became lost. Smolowitz also proposed designing a pot that does not depend on "escape-proof trapping", such as a "habipot". As an example, a pot could be developed that would also act as a shelter for lobster. He indicated the merit in this due to the fact that different sized lobster prefer different shelters according to work done by Cobb (1971).

Fortunately, some fisheries managers have been responsive to the concept of lost pots and ghost fishing. Regulations regulating the use of escape panels, delayed release mechanisms, and/or escape mechanism have been investigated and introduced into management plans over the years. However, some fisheries managers have been so eager to adopt more sustainable fishing practices to deal with ghost fishing that they have introduced regulations without investigation.

Without experimental evidence, a regulation requiring a 12 inch (30.5 cm) long section of netting laced with degradable material was proposed for the developing snow crab (*Chionoecetes opilio*) fishery in Canada (Smolowitz, 1978a). Canadian fisheries managers were concerned about preventing ghost fishing even though many researchers at the time did not think the effects of ghost fishing were significant. At the present time, biodegradable material is regulated in the snow crab fisheries in the Canadian Maritime provinces but not in Newfoundland. Legge and Batten (unpublished) are currently investigating optimal twine choice for the Newfoundland Region and preliminary data has been presented at the February 2009 RAP meetings (Dr. Paul Winger, Centre for Sustainable Aquatic Resources, pers. comm.).

Ghost fishing became a concern for the New England lobster fishery when the offshore pot fishery started to develop (Smolowitz, 1978a). Sheldon and Dow (1975) investigated the impacts of ghost fishing for the Maine lobster fishery determining that one-third or more of the lobster entering unbuoyed (lost) traps would be lost to the fishery (fishing induced mortality) due to cannibalism or from retention of lobster in lost pots. Pecci *et al.* (1978), discussed above, also studied ghost fishing induced mortality and the associated impacts when escape vents were incorporated into pots.

Ghost fishing in the west coast king crab (*Paralithodes camtschatica*) fishery became a concern in the early 1960s. The National Marine Fisheries Service (NMFS) conducted studies beginning in 1970 to investigate the potential problem as pot design had evolved and pots were more durable than when the fishery first started. However, preliminary results from the work suggested that king crab could escape from lost pots. Conflicting information from the same study noted that lost pots also contained significant amounts of marketable sized live king crab (Smolowitz, 1978a).

Survival of Tanner crab (*Chionoecetes bairdi*) in pots where the animals were unable to escape was investigated by Kimker (1994). Large, adult male Tanner crab were captured and held in Kachemak Bay, Alaska, over a 119 day period. Pots were hauled periodically and limb loss, attributed to cannibalism, was observed to increase over time. At the end of the period, 39 per cent of the animals initially captured and held had died. While the crab in this study were unable to escape, limb loss and mortality, could have been lessened if an escape gap had been used.

Stevens *et al.* (2000) conducted a ghost fishing study of Tanner crab (*Chionoecetes bairdi*) pots off of Kodiak, Alaska, using sidescan sonar to locate the lost pots. In a 4.5 square kilometre area off Chiniak Bay, 189 pots, that were assumed lost, were recovered. Although the average crab per pot was not high (1.54 crab per pot), the data did indicate that lost pots do continue to fish and retain crab over time, and thus contribute to species mortality. Further, it was noted any holes in the mesh did not significantly affect the catch per pot. The authors also reported that 34 per cent of the pots retrieved had intact mesh, after one to two years in the water. This suggests that one third of the commercial crab pots used in the region prior to 1994 did not contain an escape gap closed with degradable twine, as per regulation. Although the authors noted that the number of lost pots and crab in each pot is essential to estimate any impact of ghost fishing in a region additional information such as rates of ingress, egress, mortality rates of crab, studies on the degradation of biodegradable twine, and other components of crab pots, would also be important.

Bullimore *et al.* (2001) also investigated the impacts of ghost fishing on the brown crab (*Cancer pagurus*) and lobster (*Homarus gammarus*) fisheries off the coast of Wales, United Kingdom. The researchers set "ghost pots" to quantify mortality in lost pots over time and suggested that lost pots could continue to fish for an extended period of time as their experimental pots continued to capture animals into the second year of the study. Furthermore, the authors recommended the mandatory use of escape gaps or biodegradable panels in the United Kingdom such as the ones required in some North American fisheries. Two areas within the United Kingdom waters do have escape gap by-laws. Such legislation for all areas would be a relatively inexpensive conservation measure to introduce with a significant economic and conservation benefits realized in the long term.

Blott (1978) examined possible solutions to the problem of lost pots that continue to ghost fish off the New England coast. He considered four different time-release mechanisms for lobster (*Homarus americanus*) pots, specifically: natural twine, pot-lid hooks, wood laths, and hinged doors for the study but he only tested hinged doors. It was felt that a hinged door would be easy for fishermen and enforcement officials to check while being relatively easy and convenient to replace the latch material whether it be a piece of twine or wire (see Figure 5.1 below). He further recommended that an escape vent could be incorporated into the door. Noting the concern by fishers of wooden laths being "chewed" and thus becoming enlarged, Blott (1978) advised that the door material should not be wood. He further discussed the importance of the placement of the escape door.

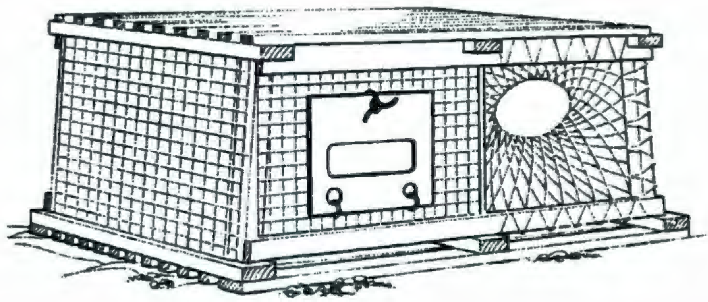

Figure 5.1 Replaceable plastic panel with an escape mechanism incorporated in a lobster (*Homarus americanus*) pot. The panel is hinged and secured in the closed position with a biodegradable or corrodible link which disables the trap from ghost fishing if lost. (*Source*: Blott, 1978).

Breen (1987) observed ghost fishing mortality of Dungeness crab (*Cancer magister*) in the Fraser River Estuary, British Columbia, for a full year. His results indicated that rigid escape mechanisms were not completely effective in enabling all undersized crab to escape from lost pots. He recommended that the pot lid be closed with an organic twine, as an example, to allow the lid to open over time and effectively reduce ghost fishing of the lost pot. He did suggest that this proposed regulation be discussed with fishermen to obtain their views and provide them with the opportunity to offer alternative solutions.

Muir *et al.* (1984) also investigated ghost fishing of Dungeness crab traps in Oregon. This was prior to the Oregon Department of Fish and Wildlife adopting the regulation that Dungeness crab pots contain a biodegradable panel to reduce potential ghost fishing of the pot if it were to become lost. Their results showed that crab can escape but some will remain in the pots and die.

Sea trials using galvanic time release mechanisms were conducted by Gagnon and Boudreau (1991) to assess the rate of corrosion of the devices for potential use for the snow crab fishery in the Gulf of St. Lawrence (refer to Figure 5.2 below). While the galvanic devices performed as per the manufacturer's guarantee, the plywood doors installed in the pots were closed with the galvanic devices. It was not known if the action of hauling the pots would increase the risk of the device releasing prematurely due to the increased stress put on the device. The authors also thought that the installation of the plywood doors would be more costly so they recommended installing the galvanic time release devices on a mended section of the mesh that would create a horizontal opening when the device was released. They also recommended further trials be conducted with commercial fishers during the 1991 crab fishing season. In 1994, the use of a biodegradable escape mechanism such as the galvanic time release device mentioned above or untreated cotton twine (size #60 or #90) woven into the base of the pot became a mandatory regulation in the southwestern Gulf of St. Lawrence region (Hébert *et al.*, 2001). The escape device described above is not to be confused with the rigid escape devices discussed for use in the Newfoundland and Labrador snow crab (*Chionoecetes opilio*) fishery.

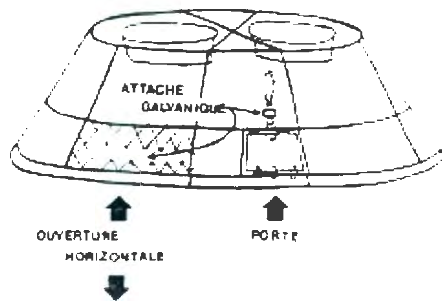

Figure 5.2 Crab pot used in the snow crab (*Chionoecetes opilio*) fishery in the Gulf of St. Lawrence showing a galvanic time release device attached to biodegradable twine in the mandatory escape panel section of the pot. The door (porte) shown in the diagram above was also closed with a galvanic device but was not recommended by the authors of the study. (*Source*: Gagnon and Boudreau, 1991).

Concern about ghost fishing prompted the voluntary installation of an escape panel in sablefish (*Anoplopoma fimbria*) pots prior to the 1984 regulation coming into effect in Canada. Scarsbrook *et al.* (1988) recommended cotton butcher's twine (1.5 mm diameter) as a binding material for escape panels as the twine disintegrated the fastest. A time release magnesium alloy device was also tested but was not deemed as effective as the more degradable twine.

In 1993, as a result of experimentation and an analysis of alternative solutions, the Alaska Board of Fisheries adopted that regulation that an escape panel be fitted in pots for all crab fisheries in Alaska. The pots could be equipped with a degradable mechanisms made of cotton twine or a galvanic time release device (Kruse *et al.*, 1994).

Guillory (1993) investigated the impact of ghost fishing for the blue crab fishery in Louisiana. Due to the technological advances in trap design, modern traps, although highly efficient, are often made of materials that do not degrade quickly. In his study, mortality of blue crab (*Callinectes sapidus*) in ghost pots was highest in the first month of ghost fishing. Therefore, even traps remaining in the water for short periods of time could significantly impact mortality of blue crab in the area. He advocated that a biodegradable panel or hinged flap with a time release mechanism be incorporated in the pot that would reduce the long-term impacts of ghost fishing. He also continued to recommend the use of escape vents to enable undersized animals to escape. His work with Acrement (Acrement and Guillory, 1993) indicated that vented pots reduced overall mortality of ghost pots by 69.2 per cent.

5.1 Preventing ghost fishing

Smolowitz's (1978b) discussion on ghost fishing in the New England lobster fishery provided several preventative solutions. Reduced effort, that is, less traps fished, is an obvious solution to reduce the numbers of pots lost that subsequently ghost fish. Determining the causes of pot losses and improving operations to reduce the losses was also suggested. Degradable sections made of materials such as wood, natural fibre, or untreated iron wire could be added to the pots. However, as the section would degrade over time a fisher would have to replace it frequently and may be tempted to replace the section with nondegradable material. Escape vents were suggested as a means of reducing ghost fishing of undersized animals. Finally, a combined escape vent and degradable section was recommended to be combined in one unit. The escape vent would allow the undersized animals to escape and, after a period of time, the degradable section will break down and enable legal sized lobster to escape from the ghost pot.

Smolowitz (1978b) further suggested that the panels should be mass produced by the States and the panels be stamped with a licence number. Harvesters would be required to purchase one catch escape panel per pot fished. This would serve several purposes in addition to preventing (or reducing) the entrapment of undersized lobster and ghost fishing by lost pots. The State would know how many pots are being fished, and subsequently, how many pots are lost. Enforcement of the regulation requiring the use of a catch escape panel in each pot would be easier with a highly visible common panel on all pots. Furthermore, the presence of the escape mechanism in the pot would reduce the number of undersized lobster in the pot which brings with it additional benefits as discussed previously.

Hébert *et al.* (2001) also advocated for the need for biodegradable escape panels in conical crab pots used in the snow crab (*Chionoecetes ophilio*) fishery in the Gulf of St. Lawrence. The results of their study demonstrated the negative effects of ghost fishing and the unnecessary mortality associated with it. Vienneau and Moriyasu (1994) similarly advocated for the installation of a self-destructing mechanism, ideally biodegradable, that would prevent ghost fishing of pots lost at sea, as did Winger and Walsh (2007).

Watanabe (2005) conducted simulated ghost fishing experiments for the red queen crab (*Chionoecetes japonicus*) fishery in the Sea of Japan. Pots were fitted with circular escape mechanisms (90, 100, and 110 millimetres) and mesh of 34 and 150 millimetres and left to soak for approximately six months. The SELECT model results showed that the majority of the crab with a carapace width of less than 99 millimetres escaped, including females. However, crab with a carapace width of more than 103 millimetres would be retained by the lost pots and therefore removed from the population.

Fish harvesters do not necessarily report lost pots and it is very difficult to undertake long term studies to assess impacts of ghost fishing (Bullimore *et al.*, 2001). Although ghost fishing is an issue of global concern and research has proven that lost pots and other gear losses do indeed contribute to fishing mortality, work can still be done to quantify the magnitude of the problem. Gear retrieval programs have been a typical management response to the problem of ghost fishing but it is equally important to consider the cost benefit of such programs which is difficult when the economic loss to the fishery from lost gear is largely unknown (Brown and Macfadyen, 2007). Regardless, the use of escape mechanisms, vents, and/or panels to reduce losses from ghost fishing, in addition to the establishment of codes of good practice and fishing fewer pots, would contribute to reduced mortality from lost pots.

6.0 Crab Fisheries Using Escape Mechanisms

Although many lobster fisheries, as discussed earlier, have mandated the use of escape mechanisms, the focus of this paper is the use of escape mechanisms in the snow crab (*Chionoecetes opilio*) fishery in Newfoundland and Labrador. Therefore it is important to highlight significant crab fisheries within North America that incorporate escape mechanisms in their fishing gear.

6.1 West Coast Dungeness Crab (*Cancer magister*) Fishery

The Dungeness crab fishery is prosecuted in the states of Alaska, California, Oregon, and Washington and in the province of British Columbia as their range reaches from the Aleutian Islands, Alaska to Santa Barbara, California (Dewees, *et al.*, 2004b). The fishery has been the most valuable single-species fishery in Washington, Oregon, and California since 1990 (Dewees *et al.*, 2004a). A recreational fishery also exists for Dungeness crab in Canada and the United States (Dahlstrom and Wild, 1983; DFO, 2000). The fishery is an important economic activity for Aboriginals in British Columbia (DFO, 2002b).

The Dungeness crab commercial fishery began in 1848 near San Francisco, California (Hankin and Warner, 2001). It began in Canada near Vancouver, British Columbia in 1885 (DFO, 2000; 2002b). Concerns about the resource prompted protective legislation for female crab as early as 1897 in California whereby the possession and sale of female crab was prohibited. Closed seasons, suggested by fishermen, were introduced in 1903, and a minimum size limit of six inches (15.2 cm) was enacted in 1905. The minimum size was increased to seven inches (17.8 cm) in 1915 which further protected female crab (Dahlstrom and Wild, 1983).

Since the 1956-57 fishing season at least one rigid circular escape port (4 inches, 10.2 cm) has been required in crab pots enabling undersized males and most females to escape in California. Variations of the escape mechanism regulation developed over time, as well as the required placement of the devices in the pot (Jow, 1961; Dahlstrom and Wild, 1983). Since 1978 all crab pots have been required to have two 4 ¼ inch (10.8 cm) escape openings. Traps must also be equipped with a destruction device that will enable a trap to open and enable retained crab to escape should the pot become lost (Dahlstrom and Wild, 1983; Hankin and Warner, 2001).

The cyclic nature of the Dungeness crab fishery since the 1940s has prompted various research initiatives, particularly during the 1970s (Hankin and Warner, 2001) in California. Ghost fishing studies have suggested the use of self-destruct devices in pots that could decompose over time if pots become lost. As well it has been recommended that the escape port size required in pots be increased to 4 3/8 inch (11.1 cm) with a time-lock on their use (Dahlstrom and Wild, 1983).

The Dungeness crab fishery is managed separately by state (nationally in Canada) but common regulations for all regions include no taking of female crab, a minimum size limit, and a closed season coinciding with the moulting cycle of the species in California, Oregon, Washington, and British Columbia (DFO, 2000; Smith and Jamieson, 1989; Kruse *et al.*, 1994; Hankin *et al.*, 1997). There are concerns in Alaska that the fishing season for Dungeness crab overlaps the major moulting period, and therefore, mortality of softshell crab is an issue (Kruse *et al.*, 1994).

Biodegradable releases and escape ports are mandated for use in pots to enable undersized crab to escape (Hankin *et al.*, 1997). In fact, crab fishers in California, Oregon, Washington, and Alaska have had a self-imposed regulation requiring the use of escape vents in Dungeness crab pots for many years (Hipkins, 1972) prior to the 1956 regulation coming into effect in California. Pots in British Columbia must be fitted with a circular escape opening of at least 100 millimetres in diameter (Breen, 1987) and have a biodegradable mechanism to prevent ghost fishing should the pot become lost (DFO, 2000).

6.2 East Coast Blue Crab (*Callinectes sapidus*) Fishery

Blue crab were harvested by Native Americans and early European settlers but the commercial industry developed in the last part of the nineteenth century. New harvesting methods, the process of canning foods, and new means to transport crab to markets significantly aided in the industry development (Cronin, 1998) in the Chesapeake Bay area in the 1880s. Nearby regions began to develop directed fisheries around 1945 followed by the southern Atlantic States and Gulf of Mexico states marketing crab by 1950. The patenting of the crab pot in 1938 by Benjamin Lewis significantly impacted the industry and quickly became the gear of choice among harvesters (Rugolo *et al.*, 1998). However, dredging and trotlines are still common harvesting methods in certain regions.

Today, the East Coast blue crab (*Callinectes sapidus*) fishery along the Atlantic and Gulf Coasts of the United States and Mexico is one of the most important commercial and recreational crustacean fisheries in North America. Blue crab is harvested commercially in all Atlantic coast states (as far north as New York) with the Chesapeake Bay area accounting for more blue crab production and marketing than any other region (Rugolo *et al.*, 1998). The decline of king and Dungeness crab stocks in the last decade has enabled blue crab products to occupy a greater percentage of the market (Steele and Burt, 1998), however, competition with other countries developing or expanding their crab resources is impacting the domestic industry, particularly with respect to imported crab meat (Oesterling, 1998; Steele and Bert, 1998). Surimi, or imitation crab meat, has also filled a niche in markets that natural crab meat cannot supply at current prices (Steele and Bert, 1998). However, marketing campaigns raising awareness of the superior quality and taste of the domestic crab product are encouraging consumers to purchase locally produced crab meat (Oesterling, 1998).

The fishery itself has many components. The commercial blue crab fishery prosecutes hard crab, peeler crab, and soft crab. Peeler crab are "hard" crab that exhibit characteristics of imminent moulting. Soft crab are animals that have recently moulted their carapace. Soft crab can be harvested in the wild but are often held in shedding tank operations with other peeler crab until moulting has occurred (Rugolo *et al.*, 1998). The recreational blue crab fishery throughout the United States is often not reported and in terms of management becomes difficult to quantify. Recreational harvests are estimated to be between four (4) per cent and 20 per cent of the commercial harvest, which is significant in terms of management (Guillory, 1998; Guillory and Perret, 1998; Guillory *et al.*, 1998; Heath, 1998; Steele and Bert, 1998).

The East Coast blue crab (*Callinectes sapidus*) fishery in the United States is managed state by state with participants from coastal states prosecuting the fishery. States bordering the Chesapeake Bay area have organized various committees and commissions to advise state legislatures accordingly of stock status and recommended management measures(Guillory and Hein, 1998b). Regulations, therefore, are state dependent. The following table (Table 6.1) provides an overview of escape mechanism regulations by state.

Table 6.1 Escape Ring Regulations for the blue crab (*Callinectes sapidus*) fishery in the Eastern United States by State. (*Source*: Guillory and Hein, 1998b. Effective July 1, 2008, all crab pots in Virginia waters require four escape rings (Harper, 2008)).

State	Number	Size	Placement	Other Info
Maryland	1 OR 5.08 X 5.08 cm square mesh with four openings in crab pots with mesh size greater than 3.81 cm or less than 5.08 cm	5.87 cm (minimum)	Side of upper chamber that may be closed at any time to catch peeler crab	
Virginia	2 of two sizes (effective July 1, 2008 pots require four escape rings) 4 rings for peeler traps	5.55 cm and 5.87 cm 3.81 cm	Upper chamber side panels of hard crab traps	Hard crab traps fished within the dredge lines of Chesapeake Bay, in Pocomoke and Tangier Sounds, and on seaside of the Eastern Shore may have the 5.87 cm ring closed for the retention of small mature females
North Carolina	2 (since 1989)	5.87 cm (minimum)	Upper chamber side panels	Outer Banks are exempt
Georgia	2 (since 1996)	6.03 cm (minimum)	Outside vertical walls	Peeler traps are exempt
Florida	3	6.03 cm (minimum)	At least one on the vertical surface of each chamber	Peeler traps are exempt
Louisiana	2	5.87 cm (minimum)	Located flush with the floor or baffles, with one in each chamber	
Texas	4	6.03 cm (minimum)	Two in each chamber located on the lower edge of the outside trap wall	

6.3 Alaskan crab fisheries

The productive waters around Alaska have supported significantly important commercial crab stocks including three species of king crab (red - *Paralithodes camtschaticus*, blue –

(*Paralithodes platypus*), and brown or golden - *Lithodes aequispina*), Tanner crab (*Chionoecetes bairdi*), snow crab (*Chionoecetes opilio*), hair crab (*Erimacrus isenbeckii*), and Dungeness crab (*Cancer magister*). Many of the fisheries expanded rapidly during 1960 to 1980 and have since collapsed or are considered depressed, the most prominent stock decline being the red king crab (*Paralithodes camtschaticus*) in the early 1980s (Orensanz *et al.*, 1998; Woodby *et al.*, 2005).

Crab stocks in the Bering Sea and Aleutian Islands, the areas accounting for the majority of commercial crab landings, are managed jointly between the State of Alaska and the United States government through the North Pacific Fishery Management Council (NPFMC). However, crab stocks in the Gulf of Alaska, including stocks in Southeast Alaska, are managed solely by the State of Alaska (Woodby *et al.*, 2005). Please refer to Figure 6.1 for orientation of the location of the various crab fisheries and regions in Alaska (below).

Figure 6.1 Locations of major crab fisheries and regions in Alaska. (*Source*: Alaska Department of Fish and Game, 2005 – found in Woodby *et al.*, 2005).

Exploratory fishing of eastern Bering Sea king crab began in 1930 by Japanese vessels. Red king crab (*Paralithodes camtschaticus*) was commercially harvested in Kodiak as early as 1936 and expanded to other areas gradually with the fishery fully established by 1950. Commercial red king crab fisheries in southeast Alaska and the Aleutians started in 1960/1961. The species is found throughout the Bering Sea, Aleutian Islands, and the Gulf of Alaska often at depths less than 180 metres. Declines in the late 1960s showed indications of stress on the stock, but market price increased while quota levels decreased and the social impacts were therefore not as prevalent during the 1970s. Additionally, the fleet moved further offshore in the late 1960s following the migration of crab into deeper waters (Otto, 1986; Orensanz *et al.*, 1998; Woodby *et al.*, 2005).

As the red king crab stocks collapsed, harvesters began to target brown king crab (*Lithodes aequispina*) around 1980/1981. The species is also located in similar areas to red king crab but at depths greater than 180 metres. The species was fished so heavily that the legal size of brown king crab was reduced in 1984. This reduction in legal size targeted new recruits rather than post-recruits. An increase in recruitment in the early 1980s enabled the fishery to continue, but as was evident, fishing effort and catch peaked in 1987 and declined to 50 per cent by 1994 (Orensanz *et al.*, 1998; Woodby *et al.*, 2005).

Blue king crab (*Paralithodes platypus*) are found as discrete populations around the islands in the Bering Sea as well as in isolated cold water areas in the Gulf of Alaska at depths of less than 180 metres (Woodby *et al.*, 2005). Worthy of mention are the stocks of blue king crab in the eastern Bering Sea. The stock around the Pribilof Islands is slightly larger in size that the stock near St. Matthew Island and the minimum legal size limit reflects the size differences. The fishery in the Pribilof Islands was developed in 1965 by the Japanese with the United Sates fishery starting to target blue king crab specifically in 1973. Oil exploration surveys led to the discovery of the St. Matthew Island population and commercial interest developed for that population in 1977 (Zheng *et al.*, 1997).

The fishery for Tanner crab began in 1967 in Alaska and catches increased faster than fishing effort in the early 1970s. However, fishing effort peaked in the early 1980s. As catches declined between 1980 to 1985, the fishery was targeting new recruits, as was the case with the brown king crab fishery (Orensanz *et al.*, 1998). Tanner crab are distributed in the eastern Bering Sea, Aleutian Islands, and the Gulf of Alaska in areas where the depth is less than 300 metres (Woodby *et al.*, 2005).

While king crab and Tanner crab represent significantly larger fisheries, snow crab are found in the northern and central Bering Sea on the continental shelf in depths of less than 300 metres primarily. Hair crab are concentrated around the Pribilof Islands in the Bering Sea (Woodby *et al.*, 2005). Additionally, although the west coast Dungeness crab fishery was previously mentioned it is important to note here that it is the oldest commercial crab fishery in Alaska, beginning in 1916 (Orensanz *et al.*, 1998). This species, as in more southern areas, is found from estuaries to open ocean areas at depths greater than 300 metres (Woodby *et al.*, 2005).

The Alaskan crab fisheries use several different types of pots depending on species targeted. However, all pots are framed in steel and covered with nylon webbing of various mesh sizes. Pots are lowered on single buoy lines for the most part, although in deeper and rough bottom areas longlines are used. Alaskan crab fisheries are male only fisheries and therefore females and undersized males are released overboard if captured in pots (Stevens *et al.*, 2000; Woodby *et al.*, 2005).

Since 1977, all crab pots in Alaska have required an escape opening 45.7 cm in length, within 6 inches (15.2 cm) from the bottom of the pot and parallel to the bottom of the pot. The opening is laced, sewn, or secured together with cotton or untreated twine so that the material degrades within 90 days and prevents the pot from ghost fishing if lost. Dungeness crab pots may substitute the opening by securing the pot lid with cotton twine, such that when the twine degrades the pot lid will not be securely closed. Galvanic time release (GTR) devices may be used, but be integral to the length of the twine such that when the device releases, no more than thirty days immersed in salt water, the twine will not be securing or obstructing the pot opening (Stevens *et al.*, 2000).

Red king crab are harvested with rectangular pots, usually from 2.0 metres by 2.0 metres to 2.4 metres by 2.4 metres, with heights from 0.7 to 1.0 metres. These pots have two funnel shaped entrance tunnels on opposite sides; one tunnel is for crab entry and the other is secured for emptying the pot when the pot is hauled. The tunnel eye opening cannot be higher than 13 centimetres in height to ensure larger crab do not enter the pot. Wooden slats are usually placed in the tunnel eye of these pots to prevent larger crab from being captured (Stevens *et al.*, 2000; Woodby *et al.*, 2005).

Pyramidal and conical pots are slightly smaller than rectangular pots and have a single square or round entrance at the top of the pot, often fitted with a plastic collar. Pyramidal shaped pots are used in Southeast Alaska specifically for Tanner crab fisheries while Dungeness crab pots are round, ranging in diameter from 1.0 to 1.5 metres and 0.4 to 0.5

metres high. Dungeness crab pots in Alaska, as required in the other western states, have escape rings to allow undersized crab to escape (Stevens *et al.*, 2000; Woodby *et al.*, 2005).

7.0 Research Efforts with Escape Mechanisms in the Newfoundland and Labrador Region

As discussed earlier, research efforts to protect undersized, non-targeted animals from capture in Newfoundland date back to the late nineteenth century when Neilsen investigated lath spacing to protect undersized lobster (*Homarus americanus*) (Templeman, 1958). In fact, Newfoundland was the first lobster fishery in eastern Canada and the United States with a regulation for "escape mechanisms". Wilder (1949) and Templeman (1939) conducted additional research in Newfoundland in the 1930s to 1940s advocating for the use of escape mechanisms in lobster pots. Other important lobster fisheries in the Maritimes and eastern United States also mandated the use of escape mechanisms following research efforts that acknowledged the value in protecting the resource (Templeman, 1958; Lewis, 1978; Elner, 1980; Maynard *et al*., 1987; Lanteigne *et al*., 1995.

As the snow crab (*Chionoecetes opilio*) fishery began to develop in Newfoundland in the latter part of the 1900s several researchers conducted investigations on the gear used to harvest the species and fishing methods themselves.

Experiments with different mesh sizes (91, 119, and 129 millimetres stretched-mesh) off the southeast coast of Newfoundland showed a decrease in capture of undersized crab with increasing mesh size (Miller, 1976). Following this, Miller (1976) recommended that 129 mm mesh size, or possibly larger, be used in pots instead of the commonly used 91 and 119 mm mesh size. He further suggested that a larger mesh size would reduce culling of undersized animals and subsequently reduce possible injury of undersized crab. Additionally, he stated that a larger mesh size would be more economical for pot construction.

From experimentation with lost pots, Miller (1977) reported that the modest loss of crab from lost pots did not justify the use of a degradable panel, such as untreated cotton twine, also noting that it would be an inconvenience to harvesters to add the section to the pot. He reported that the results of experimentation with hard and soft shell crab exposed to various air and temperature extremes indicated that undersized and soft shell crab returned to the water would survive to reach commercial size. Furthermore, Miller (1977) tested several mesh sizes to rationalize the legal minimum of 124 millimetres mesh size agreed upon by fisherman and government at the time. Although bycatch of crab in gillnets was reported, experimentation of three different types of gill nets did not yield a suitable solution to reducing crab bycatch as it would impact the harvest of other species.

A mesh size of 133 millimetres was used voluntarily by fishers in the 1980s to reduce the sorting time required when pots were hauled (Xu and Millar, 1993). While this mesh size was later regulated as the minimum mesh size required in all pots prosecuting the snow crab fishery, experimentation with mesh size was still ongoing.

Hoenig and Dawe (1991) confirmed that large (133 mm) meshed pots are selective for targeting non-soft shell, large-clawed male snow crab following a study in Conception

Bay, Newfoundland, in the spring of 1989. Xu and Millar (1993) also conducted work in St. Mary's Bay, Newfoundland, finding the commercial-sized pots (133 mm mesh) almost twice as efficient as control traps covered with 25 millimetre mesh.

Twenty-five years later, the Centre for Sustainable Aquatic Resources, an applied research unit of the Fisheries and Marine Institute of Memorial University of Newfoundland, began investigating the use of escape mechanisms in commercial decapod fisheries, principally in the Northwest Atlantic. The shape, size, location, and material of escape mechanisms studied and in use were reviewed (Winger, 2003) which set the stage for further research regarding the use of escape mechanisms in the Newfoundland and Labrador snow crab (*Chionoecetes opilio*) fishery.

In the first instance, Winger and Walsh (2007) conducted laboratory observations on the behavioural response of undersized male snow crab (less than 94 millimetres carapace width) to rigid escape mechanisms installed at two different heights in both commercial mesh pots and prototype wire traps. The escape mechanism tested was developed by the researchers to suit the current legal size limit for the snow crab fishery, that is, 95 millimetres carapace width (see Figure 7.1). Individual crab were manually inserted through a series of circular openings of two millimeter increments, ranging from 91 to 103 millimetres, to determine the minimum size opening that a crab could escape. As such, the diameter of the opening in the escape mechanism was determined to require an opening of 95 millimetres.

Figure 7.1 The circular escape mechanism tested and in voluntary use in the Newfoundland and Labrador snow crab (*Chionoecetes opilio*) fishery. The mechanism measures 250 x 140 millimetres (length and width) with two identical escape opening having an inside diameter of 95 mm each. (*Source*: Keats *et al.*, 2008).

Crab behavior in the study was recorded digitally on an underwater camera and quantified later when viewing the footage. It was determined that undersized snow crab are able to detect, approach, and escape from a rigid escape mechanism, although it was noted that several attempts were typically required for successful escape. Proper orientation of the carapace is important for escape. Three times as many escape attempts were noted through the mechanisms mounted low, that is, five centimeters off the bottom. No successful escapes were observed for the pots with the escape mechanisms mounted in the higher position, that is, ten centimeters from the bottom. Additionally, there were no significant differences between the escape attempts between the two types of pot material, that is, mesh versus wire. Winger and Walsh's work (2007) supported the use of rigid escape mechanisms as a more precise method enabling undersized crab to escape prior to harvest. They also suggested that the mechanisms could be installed with biodegradable twine or a corrodible material to render the pot ineffective for ghost fishing if lost.

Controlled at-sea experiments followed the above laboratory study to investigate the performance of two sizes of rigid, circular escape mechanisms (95 and 100 millimetres in diameter) installed in three types of pots: traditional Japanese-style conical pots hung with 5 ½ inch (14 cm) and 6 inch (15.2 cm) mesh, a similar shaped wire prototype pot, and small mesh pots with plastic collars (see Figure 7.2 below). The pots with the escape mechanisms retained fewer undersized crab with no significant reduction in the number of legal crab caught when compared to the catch of the traditional 5 ½ inch mesh pot. The wire trap performed well under controlled conditions catching fewer undersized crab. There was no significant reduction in numbers of legal sized crab retained, as compared to the catch of the traditional 5 ½ inch (14 cm) mesh pot. Finally, increasing the width of the plastic collars was deemed effective in excluding smaller crab from entering the pot. However, it was noted that if small crab happened to enter the pot (covered in 2 inch or 5.1 cm mesh) they would not necessarily be able to escape, as these pots did not contain escape mechanisms. As well, none of the collar designs experimented with achieved a respectable balance between the capture of a small number of undersized crab and high quantities of legal sized animals (Winger *et al.*, 2006).

Figure 7.2 View of a crab pot used in at-sea experiments to evaluate the performance of escape mechanisms under commercial fishing conditions. (*Source*: Keats *et al.*, 2008).

Further observations of snow crab pot entrance, escape, and collar behaviour were also conducted in this study using underwater camera systems. All crab observed entered the pots from the top of the pot, that is, no crab were observed entering the pot through the mesh or escape mechanisms. Escape behavior at-sea was similar to behavior under laboratory conditions. Undersized crab escaped either through the bottom couple of meshes of the pot or through the escape mechanisms by orienting themselves accordingly (Winger *et al.*, 2006).

Winger and Keats (2006) expanded the areas of testing for the 2005 crab fishing season. They distributed escape mechanisms to eleven harvesters in six communities along the east and south coast of Newfoundland for use under commercial harvesting conditions. Researchers assisted harvesters with the installation of the escape mechanisms to ensure compliance with rigging instructions (see Figure 7.3 below). Three mechanisms were installed horizontally in each pot equally spaced around the bottom, 1 to 1.5 meshes above the bottom ring. Harvesters provided feedback to researchers, which was supplemented by logbook data and at-sea sampling by researchers. Overall, commercial trials were successful in that fewer undersized crab were caught, on average, compared to traditional pot catches of the same mesh size in almost all regions. Harvester feedback was favourable as the use of the escape mechanisms reduced the number of crab discarded without impacting the catch of legal sized crab. As well, they noted that the use of the escape mechanisms did not affect their operation.

Figure 7.3 Installing escape mechanisms in snow crab (*Chionoecetes opilio*) pots as part of a commercial trial project in Newfoundland and Labrador. (*Source*: Keats *et al.*, 2008).

Catch results from the 2005 and 2006 fishing seasons were compared for the harvesters using escape mechanisms in their gear from Petty Harbour, Newfoundland and Labrador (Hiscock *et al.*, 2006). Results from the 2005 season were more favourable as the data depicted fewer undersized crab and more legal sized crab in pots fitted with escape mechanisms than in the 2006 fishing season. Anecdotal information from harvesters in the area suggested that there were more undersized crab on the fishing grounds in 2006.

Therefore, the researchers suggested that pots fitted with escape mechanisms should continue to be fished alongside traditional pots, such that more information can be gathered for multi-year comparisons. All in all, harvester feedback continued to be positive and harvesters recommended that the voluntary use of escape mechanisms should be permitted for the Newfoundland and Labrador snow crab fishery.

Further expansion of the use of escape mechanisms in snow crab pots across Newfoundland and Labrador continued in 2007 and 2008. In fact, as part of a controlled program, thirty-six harvesters in twenty-five communities through the province used escape mechanisms in their crab pots (see Figure 7.4 below). Harvester feedback reported for 2007 was equally favourable to the results from the 2005 and 2006 fisheries with harvesters agreeing that escape mechanisms are effective selectivity devices in their regions and would therefore be of benefit to other regions (Keats *et al.*, 2008).

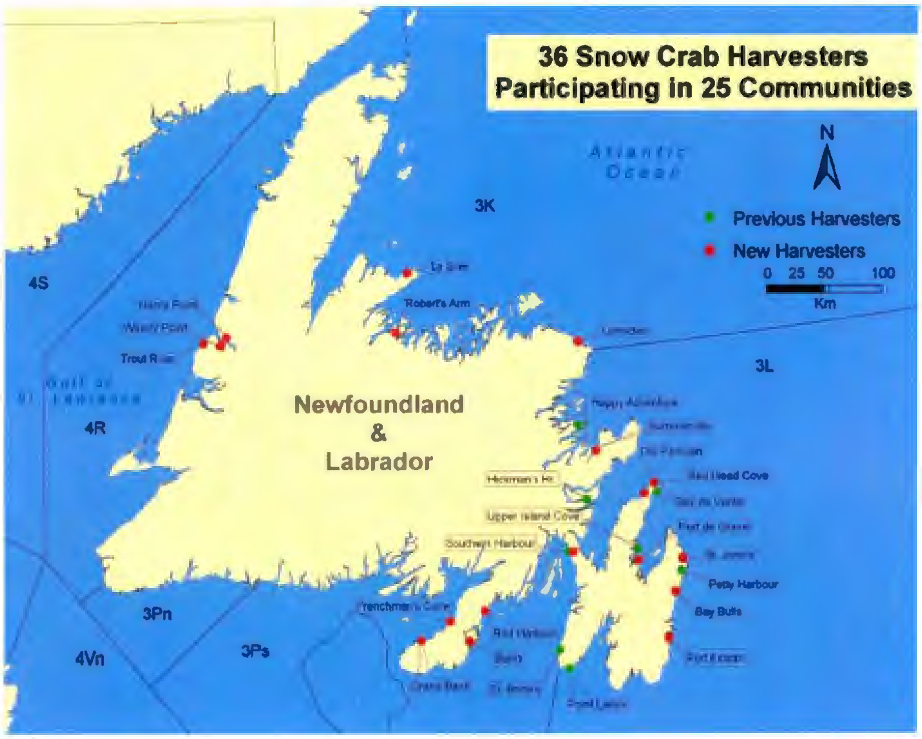

Figure 7.4 Distribution of 36 harvesters using escape mechanisms in crab pots throughout Newfoundland in 2008. (*Source*: Keats *et al.*, 2008).

Efforts are underway to expand the use of escape mechanisms across the province again for the 2009 crab fishery. Coincident with this, DFO has made the use of escape mechanisms a voluntary management measure across the province for 2009. Snow crab harvesters, on a volunteer basis, can install escape mechanisms from the Centre for Sustainable Aquatic Resources (refer to Figure 7.1) in their pots. This is the first year this voluntary conservation measure has been instituted across the Newfoundland and Labrador region (Brooks Pilgrim, Resource Management, DFO, pers. comm.).

8.0 Declining Crab Stocks

The Total Allowable Catch (TAC) for snow crab in the Newfoundland and Labrador region peaked in 1999 at 61,200 tonnes (DFO, 2007a). As with the cyclical nature of crab stock growth and decline in abundance (Gardner Pinfold, 2006), the stock was at a lower level before it increased significantly from the mid-1990s to 2000 (DFO, 2007a). During that same time period, many harvesters entered the snow crab fishery and the industry became dependent on the resource (FRCC, 2005; Gardner Pinfold, 2006).

The yearly fall multi-species surveys in Divisions 2J3KLNO have indicated a resource decline in exploitable biomass since 1998. Quota management is an important sustainable management strategy of DFO in response to indications of stock decline in line with the precautionary approach. Measures were implemented in 2000 to address the forecasted decline in the stock biomass and the overall TAC was adjusted. Additionally, recruitment declined from 1996 to 2002 and remains at a low level, although short term recruitment prospects have improved in some divisions. Long term recruitment prospects however are uncertain (DFO, 2005; 2006; 2007a).

From a fisheries management perspective, as evidenced from the demise of Alaskan crab stocks, it is important to learn from other jurisdictions. Crab fisheries rely on an accrued biomass of old, large individuals upon initial expansion (Orensanz *et al.*, 1998). As crab species are long-lived, once the majority of these individuals have been harvested the structure of the stock will change and the fishery will begin to rely on new recruits. In some cases, exceptional year classes will result and the stock biomass will increase, which brings with it an expectation of increased quotas. Expansion of the fishery into previously unexploited areas and further and further offshore will also impact and possibly obliterate stocks completely (Orensanz *et al.*, 1998).

Beyond the basic biology of the species and indications of declines in stock biomass are other factors impacting the fishery that are not under the control of scientists, fisheries managers, and the industry itself, such as disease, regime shifts, and to some extent, fishery mortality.

8.1 Disease

Incidences of bitter crab disease (BCD) in the Newfoundland Region have been more broadly distributed during 1996 to 2006. The disease has been most prevalent in Division 3K but has increased, particularly in Division 3L, and appears to have extended southward recently (DFO, 2006; 2007a). The disease is of concern because infections have been documented as highest in females and undersized males. Shields *et al.* (2004) conducted a mortality study and concluded that all naturally infected crab died while 50 per cent of experimentally infected crab died. Death due to BCD represents another level of uncertainty in determining recruitment prospects and will have an impact on the resource should outbreaks of the parasitic dinoflagellate continue to spread to more divisions.

8.2 Regime Shifts

A negative relationship of six to ten years lag time has been demonstrated between bottom temperature and catch per unit effort of snow crab. This has led scientists to infer that cold temperatures during the early life history of snow crab may be linked to strong year classes for the capture fishery (DFO, 2005). A warm period over the past decade therefore implies poor recruitment prospects (DFO, 2007a) which does not bode well for the fishery in the coming years (Dawe *et al.*, 2005).

A regime shift has also been postulated for the crash of Alaska's Bristol Bay red king crab (*Paralithodes camtschaticus*) population in the early 1980s (Muter *et al.*, 1995) although the debate between laying the blame on a regime shift or on overfishing is still unresolved (Dew and McConnaughey, 2005). In fact, Poulsen (1995) advocates that the red king crab fishery was impacted greatly by bycatch issues and the lack of acceptance of fishery managers in recognizing the problem.

Regardless, the Bristol Bay red king crab fishery, Alaska's second highest value fishery during the 1970s, bottomed out in 1983 (Dew and McConnaughey, 2005). It is important to note the similarities between the red king crab (*Paralithodes camtschaticus*) fishery in Alaska and the snow crab (*Chionoecetes opilio*) fishery in Newfoundland in terms of economic and social dependency on a single species resource. For this reason every precaution should be taken by fisheries managers and industry to conserve Newfoundland and Labrador's snow crab resource.

8.3 Fishing Mortality

Uncertainty regarding fishery-induced mortality still exists. Although handling practices have reportedly improved, it is difficult to estimate fishery-induced mortality (DFO, 2005; 2006). Nevertheless, handling mortality of pre-recruit, female, and soft-shell crab is considered high (Dawe *et al.*, 2005; DFO, 2006; 2007a) and represents wastage of the resource. Handling mortality can be reduced by increasing the mesh size of pots, increasing soak time, reducing high-grading, and handling undersized crab carefully and releasing them quickly once caught (DFO, 2006; 2007a). A certain percentage of crab caught and released will die or sustain injuries. This will leave them critically weak and subject to predation or stressed which may interfere with feeding and other activities which may result in death and/or diminished reproductive capability in the longer term (Dufour *et al.*, 1997; Grant, 2003). Soft-shell crab, that also must be returned to sea if harvested, are especially vulnerable to higher temperatures at low salinity than hard-shelled crabs (Hardy *et al.*, 1994). Onboard handling conditions may therefore make soft-shell crab even more vulnerable to mortality and predation when discarded at sea.

Undersized crab that may or may not be sexually mature are vulnerable to capture in the fishery often before they reach commercial size (Saint-Marie *et al.*, 1995; Grant, 2003). Taylor *et al.* (1989) have reported that repeat capture of individuals in the same season has been documented. So, in addition to handling and discard mortality factors, repeated capture of undersized crab and subsequent exposure to handling, holding, and releasing practices can also impact the quantity of legal-sized crab available to the fishery in future years (Grant, 2003).

Ke *et al.* (1981) also examined handling and holding practices of harvesters from a processing perspective. Just as undersized animals are impacted by dropping and exposure, test and field observations indicate that legal sized snow crab (*Chionoecetes opilio*) have extremely low (five per cent) survival rates when they lose two legs and 50 per cent survival when they lose one leg or have been dropped from a height of one metre. Handling techniques on board vessels are equally important for legal sized crab as for undersized discarded crab because legal animals must be processed live and reach the processing plant in a live state. The quality of the finished (processed) product is dependent on the initial quality of the live animal immediately before it is processed.

Kennelly *et al.* (1990) conducted laboratory and field experiments with discarded spanner crab (*Ranina ranina*) in Australia and reported significant mortality rates of animals subjected to injuries, namely limb loss, due to handling of bycatch. Durkin *et al.* (1984) reported a high incidence (66 per cent of the total catch) of Dungeness crab (*Cancer magister*) either missing or regenerating legs in the Columbia River Estuary noting such limb loss or regeneration could significantly impact the animal's ability to move, feed, moult, compete for space, protect itself, and ultimately survive. Similarly, Shirley and Shirley (1988) reported a 25 per cent incidence of injured limbs, either missing, regenerating, or damaged, of the Dungeness crab sampled in Southeast Alaska. They further noted that appendage injuries were correlated with date such that more injuries occurred during moulting, mating, and fishing.

Kruse *et al*. (1994) documented that mortality of softshell animals from a Dungeness crab study in Alaska was directly related to the incidences of capture, handling, and subsequent release into the ocean. Based on their experiments, they calculated that softshell crab had a 45 per cent higher mortality than hardshell crab due to handling and exposure effects. Zheng *et al*. (1995) suggested that extreme handling mortality may have accounted for the increase in unexplained mortality that was significant in the collapse of the Bristol Bay red king crab (*Paralithodes camtschaticus*) population collapse in the early 1980s.

As a specific case in point, Warrenchuck and Shirley (2002) conducted work to estimate the discard mortality of snow crab (*Chionoecetes opilio*) during the Bering Sea Fishery in Alaska in 1998. While snow crab are caught and discarded in other fisheries in the Bering Sea, it is thought that the snow crab fishery itself accounts for most of the bycatch, specifically of undersized snow crab. Recognizing the stress on the undersized animals experienced during the harvesting, holding, sorting, and discarding process, including injuries from handling, as well as the extreme weather conditions prevalent during the winter fishery, the authors estimated a bycatch mortality of 22.2 per cent. They noted that this estimate was likely conservative, as they did not consider the synergistic effect of handling and exposure to cold temperatures and wind. As well, the mortality estimate was for direct mortality resulting from the capture and discard process. Prolonged effects of handling and exposure such as reduced growth, mating success, and vulnerability to predation could also impact mortality of animals.

Grant (2003) quantified mortality of undersized and high-graded snow crab by considering drop height and air exposure in relation to conditions prevalent on commercial fishing boats in Newfoundland and Labrador. Instant and delayed mortality of crab increased substantially with an increase in drop height and air exposure duration. Results showed that survival can be maximized when crab are treated gently and released back into the water quickly (within five minutes). Earlier researchers demonstrated that time out of water, air temperature, water temperature, shell hardness, wind speed, sunlight, and the size of crab influence discard mortality rates of crab as well (Miller, 1977; Dufour *et al.*, 1997). Tallack (2007) also reported high mortality rates from drop effects for deep water queen crab (*Chaceon quinquedens*), particularly for females.

9.0 Approaches to Bycatch Reduction

9.1 Education and Training of Harvesters

Adequate education and training on the front-end of developing a sustainable fishery to include new entrants is critical. Fishers should be aware of how to handle the animal to bring a premium product to market. When pots are emptied into the vessel, fishers need to be aware that the survivability of both the product they retain and the resource they return to the water impacts their livelihoods.

Brown and Caputi (1983; 1985; 1986) have conducted studies on the survival and subsequent growth of undersized western rock lobster (*Panulirus cygnus*) that survive exposure to the atmosphere, damage, and/or displacement following capture in pots. The significant fishing-generated mortality determined by the researchers, discussed previously, led to an eighteen month education program being carried out in 1981 and 1982 that publicized the effects of poor handling methods on the survival of undersized lobster. The program encouraged fishers to return undersized animals immediately to the sea in the immediate vicinity of where the animal was caught. They found that the education program did improve handling of undersized animals. One noted and recommended change was to sort directly from the pot or sort after each pot was hauled instead if sorting after the line of pots was pulled. More than 50 per cent of the sample group of fishers monitored however (52.5 %) still did not use the recommended method of minimizing exposure time of the undersized animals before being returned to the ocean. The authors recommended further education and publicity to further enhance recruitment to the fishery. Lyons (1986) also suggested that educational programs were critical toward long-term resource productivity for the spiny lobster (*Panulirus argus*) fishery in South Florida.

9.2 Reducing Handling Mortality

The survival of discarded animals is particularly important to the future success of the fishery. The most practical way to reduce mortality, injury, and/or stress to non-commercial crab caught in the fishery is to avoid their removal until they reach commercial size for the fishery. This leads one to consider options that work to effectively reduce the number of undersized crab being caught in commercial crab pots.

Much of the gear technology research work to date has been aimed at reducing the number of undersized crab caught in crab pots with the added bonus aim of reducing the overall mortality rate associated with discarding undersized crab. Further to this, studies on modifications to crab pots have been conducted including the development of escape mechanisms for undersized crab.

9.2.1 Pot Modifications

Chiasson *et al.* (1993) investigated the use of various sized vertical panels (or excluder rings) installed at different heights on the slope of the conventional pot used in the Gulf of St. Lawrence fishery. The plastic panels were developed as selectivity devices to reduce the capture of softshell and/or undersized crab, thereby discouraging them from climbing the slope of the pot. The height of the panels used considered the length of the extended walking legs (from tip to tip) of a minimum legal sized (95 mm) male snow crab. The study found a trend of decreased softshell and undersized crab with increased panel height, and therefore concluded that the vertical panel was a good alternative pot modification in conserving future recruits to the fishery.

Hébert *et al.* (2001) evaluated the catch performance of three types of commercial traps (conical, pyramidal, and rectangular). They found that the pyramidal and conical pots were more efficient than the rectangular pots in catching larger crab. The conical pot was modified with plastic panels to serve as a barrier to be more selective to reduce the catch of undersized and soft-shelled crab. Four different sized panels were investigated and the use of a plastic panel of 18 or 24 centimetres attached vertically to the top of a pot was shown to catch significantly less soft-shelled and undersized crab than a conical pot without a panel. The pots with the panels still maintained the same catch rates for commercial crab while avoiding unnecessary discard mortality of soft-shelled and undersized snow crab. This has longer term stock conservation implications. Hébert *et al.*'s work with ghost fishing in this study, as discussed previously, also stressed the need to incorporate biodegradable escape sections in pots to avoid unnecessary mortality.

Zhou and Shirley (1997) also investigated pot design as a way to reduce the bycatch of female and undersized male red king crab (*Paralithodes camtschticus*). By considering crab behaviour towards pots and crab morphology, their new pot design incorporated smaller mesh size, lower and wider entrance tunnels, and precise gaps between one-way opening triggers to reduce untargeted catch by over 60 per cent. The catch of legal males increased by over 25 per cent compared to the catch of a standard red king crab pot. The authors noted however, that a large scale field test was required to further test the effectiveness of a new pot design.

In a related at-sea study, Zhou and Kruse (2000) tested an experimental pot design in the eastern Bering Sea. The experimental pots had four tunnels instead of two, positioned lower than standard red king crab pots. Opening triggers were spaced 10 centimetres apart. Unlike the previous study, the experimental pot design did not reduce the catch of undersized crab or increase the catch of legal sized animals. The authors encouraged observation work to be undertaken using a remotely operated vehicle to adequately observe crab behaviour on the sea floor. This information could be used to redesign an experimental pot to be more effective under commercial fishing conditions.

9.2.2 Increasing Mesh Size

Sinoda and Kobayasi (1969) conducted experiments on the mesh selectivity of crab pots with mesh sizes of 46, 90, 120, and 150 millimetres for the Beni-zuwai crab (*Chionoecetes japonicas*) fishery in the Japan Sea. As the authors wished to prevent the capture of immature males below 103 millimetres, they concluded that a mesh size of over 196 millimetres would be required in the fishery to maintain crab stocks. The recommended mesh size was estimated based on the 50 per cent selection point for mesh selectivity of the pot.

Years later, Sinoda *et al.* (1987) tested snow crab (*Chionoecetes opilio*) pots with four different stretched mesh sizes of 3, 10, 13, and 15 centimetres in the Japan Sea. The legal size of snow crab in the region was 9 centimetres. Results showed the pot with the 15 centimetre mesh retained 78 per cent legal sized crab, and thus was efficient in enabling undersized animals to escape. Furthermore, they determined that changing the mesh size of the pot would increase the catch 50 per cent by weight and 36 per cent by numbers. Therefore, the authors recommended a change in the mesh size of the pot to be more selective for the target-size animals, thereby protecting the undersize crab from the catch and discard process.

Similarly, Jeong *et al.* (2000) conducted mesh size studies for the benefit of the red queen crab (*Chionoecetes japonicus*) fishery off the east coast of Korea. Six different mesh sizes (95, 112, 122, 132, 152, and 172 millimetres mesh opening) were compared. Results showed that increased mesh size would enable more undersized and lower valued crab to escape with no decrease in fishing efficiency. Enlarging mesh size in pots therefore would decrease bycatch of undersized and female red queen crab in a step towards better conservation of the resource. Although not tested in the study, the authors thought that under high trap capacity conditions the large area of mesh would be more selective in reducing bycatch of undersized animals than an escape gap or vent.

Groeneveld *et al.* (2005) conducted a study pertaining to the 1984 regulation change in the Cape rock lobster (*Jasus lalandii*) fishery in South Africa. At that time, the mesh size requirement changed from 62 millimetres stretched mesh to 100 millimetres stretched mesh in an effort to reduce the catch of undersized lobster. However, in more recent years 35 to 40 per cent of the commercial catch was undersized and required release. Upon investigation, while the authors determined that theoretically the stretched mesh of 100 millimetres was adequate in allowing undersized animals to escape, all animals able to escape did not. It was noted that some undersized animals did use the trap entrance to escape however.

Miller (1976) and Hoenig and Dawe (1991), previously discussed, conducted mesh size studies in Newfoundland with snow crab (*Chionoecetes opilio*) and advocated for a larger mesh size in pots to reduce the number of undersized crab caught and subsequently subjected to possible injuries. Taylor *et al.* (unpublished m.s.) also suggested an increase in mesh size from 5 ¼ inches (13.3 cm) to 5 ½ inches (14 cm) following investigations in Bonavista Bay and Conception Bay (NAFO Division 3L).

9.2.3 Soak Time Studies

Increasing soak time has also been suggested as a method to allow undersized crab more time to escape through the mesh of the pot before the pot is hauled to the surface (Hébert *et al.*, 2001).

Bennett (1974) analyzed log book data from fishermen in Devon, England to determine the effect of soak time on catch per unit effort of crab (*Cancer pagurus*) and lobster

(*Homarus gammarus*). The catch per unit effort of lobster decreased after the first day of immersion but the crab pots continued to fish up to four days.

Miller (1980) reviewed several previous studies and noted as well that catch does not increase proportionally to soak time. In fact, he stated that catch stabilizes with increasing soak time. Following experimental work comparing trap catches and soak times, Miller (1983) reported that no significant differences were apparent for pots that were soaked one day or longer.

Pengilly and Tracy (1998) studied the effect of soak time on the catch of red king crab in the traditional fishing grounds of Bristol Bay, Alaska. Their results indicated that the use of longer soak times will result in less bycatch of undersized animals as per the predictions of fishers. It should be noted however that the catch of legal or undersized crab did not increase or decrease proportionately, that is, doubling or tripling the soak time of the pots did not double or triple the catch or reduce the bycatch accordingly. In fact, they reported that soak times of up to 72 hours were not sufficient to eliminate the capture of undersized red king crab in the Bristol Bay fishery. Further to this, the authors noted that the effectiveness of the required escape panel should increase with increasing soak time as undersized animals are provided with greater opportunity to escape.

Poulsen (1995) also deemed a combination of large pot mesh size and increased soak time as part of the solution to decrease bycatch in the Alaskan crab fisheries. He noted that the management measures to introduce pot limits to the crab fisheries in the Bering Sea and Aleutian Islands region however instigated harvesters to haul their gear more often, as often as twice a day, prior to the introduction of pot limits, thus not allowing sufficient soak time for nontargeted animals to escape from pots. He did point out that the introduction of an individual transferable quota (ITQ) system would enable fishers to increase pot mesh size and soak times as they wouldn't be impacted by factors such as time and pot limits. This ITQ based management system would then be a potential solution to mitigate bycatch.

Zhang *et al.* (2002), in their study of the Dungeness crab (*Cancer magister*) fishery in Fraser Delta, British Columbia, noted that there are several factors that can make a crab fishery vulnerable to overfishing. Two of them, handling mortality and the number of undersized crab caught in traps, could be managed through appropriate measures such as closing the fishery when a high percentage of softshell crab are being caught, increasing the regulatory size of escape rings, and increasing the soak time of pots.

Taylor *et al.* (unpublished m.s.), discussed above, recommended a soak time of three days for snow crab harvesters in the Newfoundland and Labrador following investigations in Bonavista Bay and Conception Bay (NAFO Division 3L). While they recognized handling mortality was a concern, the authors observed reduced undersized crab and increased catches of legal sized crab following a three day soak period of pots hung with the suggested 5 ½ inch (14 cm) mesh.

Some fishers have noted it can be impractical to soak pots for three days, especially for distant fleets that conduct multi-day trips. If the enterprise approaches inclement weather pots may need to be hauled sooner than desired as well (Dr. Paul Winger, Centre for Sustainable Aquatic Resources, pers. comm.).

It is important to thoroughly study the particular species targeted in each specific area if one is to recommend increased soak time as a management measure to reduce bycatch of undersized crab in an effort to sustain the stock. It should be noted however that with pot limits and a relatively short fishing season, particularly if the season is late starting due to weather, soak time in the Newfoundland and Labrador snow crab fishery is difficult to enforce and therefore may not be the most appropriate management measure to mitigate the bycatch of undersized snow crab.

9.2.4 Use of Escape Mechanisms

As outlined above, the majority of developed crustacean fisheries throughout the world require the use of escape mechanisms in their gear to reduce the capture of undersized, non-targeted animals in the pots. Many crab fisheries worldwide have expanded since the early 1990s with the development of new markets and increased value of the resource. These fisheries, as well as other decapod fisheries, are incorporating sustainable practices.

The demand for crab product and its associated high market value will prompt the development of "new" commercial fisheries that will entice participants to increase fishing effort on stocks that have never been exploited. As has been the pattern with other crab fisheries, particularly with modern and efficient gear, a few decades of cyclical catch will likely be followed by a period of dramatic decline. Few depleted stocks have shown adequate signs of recovery once they have been depleted to any extent. The importance of the precautionary approach is therefore appropriate to reiterate if one is to prosecute a sustainable fishery.

New regulations for escape mechanisms came into effect for the Bering Sea snow crab fishery in 2001 as part of the stock rebuilding plan. Pots using circular escape mechanisms were required to be fitted with eight escape rings rather than four with inside diameter of the escape rings required increasing from 3 ¾ inch (9.5 cm) to 4 inches (10.2 cm). The rings were to be placed within one mesh of the bottom of the pot. For pots using larger mesh rather than rings, mesh size on the side of the pot increased from 5 inches (12.7 cm) to 5 ¼ inches (13.3 cm) and the required area of the larger mesh increased from 1/3 of the side panel to ½ of the side panel (Byersorfer and Pengilly, 2001).

These new regulations were due, in part, to the significantly high bycatch of legal-sized (but not industry standard sized) male snow crab (*Chionoecetes opilio*) in the Bering Sea snow crab fishery between 1995 and 1999. The industry standard size of retention for the fishery was a carapace width of 4 inches (10.2 cm), while the legal size for capture was a carapace width of 3.1 inches (7.9 cm). Male crab harvested with a carapace width between 3.1 and 4 inches (7.9 and 10.2 cm) were discarded and therefore subjected to handling and exposure (Byersorfer and Pengilly, 2001).

However, these new regulations came into effect without direct studies on the snow crab in the Bering Sea and were thus met with apprehension from harvesters. It was not known if the new requirements, which would impose additional costs on the industry, would provide any reduction in bycatch. A subsequent study by Byersorfer and Pengilly (2001) however did provide evidence to support the newly introduced escape ring regulations, particularly the placement of the escape rings to a lower position in the pot. They found that the additional number of rings and the increased diameter of the rings did not significantly impact the catch per unit effort (CPUE) of legal sized crab.

Regulations also came into effect in 1996 for Area J Tanner crab (*Chionoecetes bairdi*) fisheries in the Bering Sea without tests to assess the effectiveness of the regulations (Pengilly, 2000). Tallack (2007) reported that escape rings were fitted in traps for the New England fishery for deep-water red crab (*Chaceon quinquedens*) without evaluation as to the most effective ring size. Results of experiments with three different sizes of escape rings by Tallack however showed the standard size in use (9 cm in diameter) was the most efficient, noting that if minimum legal size changes, the size of the escape mechanism used may also require a change.

Exploratory fisheries for rock crab (*Cancer irroratus*) and Jonah crab (*Cancer borealis*) in the Maritimes during the 1990s required the use of circular escape mechanisms in conical pots. It is noteworthy that from the beginning of the fishery regulations were put in place to protect undersized animals and the future of the resource. In fact, when the fisheries commercialized in 2004, fishers in LFA 36 (in the Bay of Fundy) began using larger escape mechanisms than those mandated to avoid sorting out small crab in their pots (Adams *et al.*, 2000; Robichaud *et al.*, 2000; Robichaud and Frail, 2006).

Recognition that bycatch mortality is an issue in the Bering Sea snow crab fishery and the recent measures introduced to reduce bycatch are significant and may help to incorporate these measures into management strategies in other jurisdictions. Mandating the use of escape mechanisms in exploratory and/or newly developing fisheries, as appropriate, is also encouraging. However, testing the effectiveness of proposed regulations before adopting them would be a significant step in ensuring credibility with harvesters who ultimately embrace or oppose changes that impact their livelihood.

10.0 Recent Management Responses to Declining Snow Crab Stocks in Newfoundland and Labrador

One of the four long-term objectives for the management of the snow crab fishery in Newfoundland and Labrador is "to conserve the snow crab resource to provide commercial sustainability to fish harvesters" (DFO, 2006). In order to achieve this objective several management measures have been put in place.

Aside from fishery mortality, minimizing sources of fishing induced mortality is key to conserving the resource. In recent years the crab fishing season has been shortened and areas with a high incidence of soft shell crab have been closed to minimize discard mortality of soft-shelled crab. Proper handling practices were to be promoted throughout the industry and bycatch of crab from other gillnet and trawl fisheries were to be minimized as well. High grading was also to be discouraged (DFO, 2006) as part of these management measures to sustain the snow crab resource.

Regulations prohibiting retention of crab under 95 mm in width were established early in the history of the fishery to maintain the reproductive capacity of the resource (DFO, 2006). A minimal legal mesh size of 135 mm has been instituted which, according to DFO, is sufficient to enable undersized crab to escape (Dawe *et al.*, 2005; DFO, 2005). However, as mesh is a flexible material, it would be the tightness of the mesh that would affect the size selectivity of escapement. More so, the tightness of the mesh is determined by how it is hung on the frame of the pot. While undersized crab are able to escape from mesh openings the size selectivity of animals that escape is not as precise as for rigid openings (Miller, 1990), such as the rigid escape mechanisms discussed here. Mesh may shrink over time or may not be fitted properly in the pot further decreasing the selectivity of the mesh (Winger and Walsh, 2007) for its intended purpose, that is, enabling undersized animals the opportunity to escape prior to harvest while retaining legal sized crab.

As well as legal sized soft shelled crab that is caught and returned to the water, as previously stated, an effective way to minimize some fishing induced mortality would be to use escape mechanisms in commercial crab pots.

The 2006 and 2007 Stock Assessment reports for the snow crab fishery in Newfoundland and Labrador both include the use of escape mechanisms and biodegradable panels as options for reducing fishery-induced mortality of undersized crab (DFO, 2006; 2007a). Over a century of research efforts, detailed above, have recommended the incorporation of escape mechanisms into pots leading to regulations in other jurisdictions with important lobster and crab fisheries. Additionally, recent work by researchers with the Centre for Sustainable Aquatic Resources, in concert with harvesters, has generated interest throughout the Newfoundland and Labrador region.

11.0 Recommendations and Conclusions

11.1 Incorporation of escape mechanisms

Uncertainty remains about the effect of changes in fishing practices such as soak time, mesh size, bait quality, and high grading, in terms of catch rates and resource status. It is also uncertain how handling practices have changed over time.

Other sources of mortality such as predation, oceanographic conditions, and disease are difficult to control. The use of a rigid escape mechanism however does provide some element of control in terms of reducing capture and release event related mortality. Additionally, escape mechanisms have the potential to prevent or decrease the effects of ghost fishing of lost pots if sewn in using biodegradable twine or attached with some sort of corrodible material.

Numerous researchers have contributed to the knowledge base of behavioural and physiological characteristics exhibited by decapods when approaching a trap, becoming entrapped, and in some cases, escaping from a trap, as described above. By understanding the trap capture process researchers and fishery managers alike are able to achieve stock conservation objectives while realizing cost-saving benefits for the industry.

11.2 Continue education initiatives

While the use of escape mechanisms in snow crab pots will reduce the capture of undersized animals it will not completely prevent non-targeted animals from being retained in the pot. Therefore, education initiatives must continue to minimize handling induced mortality of the animals that are caught, culled, and discarded. Care must be taken throughout the sorting and discarding process as well to minimize exposure time of the animals to high temperatures and air and reduce drop factors that could also impact mortality of undersized and soft shell animals.

11.3 Instilling a conservation ethic

Yet another impact on the long term sustainability of the crab fishery in Newfoundland and Labrador is the mentality of conservation. Although conservation is DFO's primary goal in the management of the crab fishery many of their management approaches are not built on strong science. There are limited funds for surveys and most of the indices of stock biomass and size distribution are developed based on multi-species bottom trawl surveys which do not catch many crab. Some small scale pot surveys are conducted but they are restricted in scope as well. Observer coverage is reported to be low and highly seasonal so it is difficult to estimate high grading and ensure other conservation based practices such as softshell protocols, handling and holding of undersized animals, and discarding of bycatch before steaming are actually followed. Additionally the hanging ratio of mesh is not stipulated in management documents. The way in which the mesh is hung on the pot's frame impacts the selective properties of the pot. As well, crab pots aren't required to be tagged like gillnets are in the Newfoundland and Labrador Region, for example. Therefore fishing effort is hard to manage and if pots are lost there is no retrieval program in place to reduce ghost fishing by lost pots (Dr. Paul Winger, Centre for Sustainable Aquatic Resources, pers. comm.).

In the industry, the message of sustainability is not well understood. Some fishers do not appear to have a vested interest in the longevity of the natural resources that could sustain their communities for years to come. However, stewardship initiatives are increasing in the province and an apparent change in attitude is encouraging. The Fish, Food and Allied Workers Union (FFAW/CAW), the Provincial Department of Fisheries and Aquaculture (DFA), the Canadian Centre for Fisheries Innovation (CCFI), the Department of Fisheries and Oceans (DFO), the Marine Institute (MI), the Fogo Island Co-operative, Petty Harbour Fisherman's Co-operative, and individual harvesters have been working collaboratively to expand the use of escape mechanisms across Newfoundland (Dr. Paul Winger, Centre for Sustainable Aquatic Resources, pers. comm.).

The notion of conserving the snow crab stock for the future is fundamental. By actively participating in sustainability initiatives and working cooperatively with agencies and organizations interested in resource conservation a conservation ethic becomes instilled within the industry itself. The fishing industry, in effect, becomes a steward of the resource for future generations.

11.4 Preventing pot loss and ghost fishing

In addition to reducing the capture of undersized crab and, in effect, reducing associated handling mortality, the issue of ghost fishing should also be addressed. Effort should be dedicated to retrieve lost gear by investigating technology and other methods to help locate lost gear, prevent the likelihood of losing gear, and report pot losses to include the location where gear is lost. Sewing rigid escape mechanisms into crab pots with biodegradable twine effectively enables the pot to become an anti-ghost fishing device should it become lost. Once the twine has eroded and the proposed rigid escape mechanism has dropped away from the mesh a 25 x 14 centimetre gap in the pot mesh will allow any animals captured in the lost pot the opportunity to escape.

While previous studies have had difficulty estimating the length of time a lost pot can effectively fish, and therefore contribute to "fishing" mortality, the issue of ghost fishing needs to be more highly recognized by the local industry in that there is likely a significant impact on stocks. Furthermore, estimates of ghost fishing mortality should be factored into stock assessments (Laist, 1995).

11.5 Conclusion

With such a rapid expansion of the snow crab industry in Newfoundland and Labrador in the 1990s, the industry ramped up quickly. Vessels prosecuting the fishery were of various designs and due to space limitations, in some cases, quality assurance of obtaining a live and healthy full-limbed animal product to satisfy market demand was a challenge. In some cases crab are held out of the water for 30 to 60 minutes before sorting, as one or more trap lines are hauled, and once sorted are tossed overboard from a vessel at a height of about eight feet before hitting the water. Rough handling practices have been attributed to the belief that snow crab are tough and durable and are capable of withstanding rough handling (Grant, 2003).

Although the handling education initiatives presented by DFO in its snow crab management plan for 2003-2005 are to have continued during the 2006-2008 period (DFO, 2006), efforts were likely not strong enough to effect a substantial short-term change in harvesting practices. As well, research efforts with pot modifications, mesh size, and soak time in other decapod fisheries throughout the world have not transformed management regulations to the same extent as escape mechanisms.

While it may be seem that this paper is suggesting that a new regulation regarding escape mechanisms for the snow crab fishery of Newfoundland and Labrador Region be adopted, it would be difficult to expect harvesters to abide by yet another regulation that involves time, money, and the unknown. The individual harvester may not see the benefit of using escape mechanisms in their individual enterprise. Enforcement of regulations is expensive and therefore it is not assured that all harvesters would abide by new regulations. Expanding the use of escape mechanisms throughout the province as the researchers from the Centre for Sustainable Aquatic Resources have done has enabled harvesters to assess the effectiveness of the mechanisms for themselves. Engaging harvesters in the experimental process takes advantage of their unique knowledge of assessing the relevant fishing technology under commercial fishing conditions. With successful and proven results harvesters are then likely to encourage others to use the technology on a voluntary basis as well (Kennelly and Broadhurst, 1995).

The snow crab resource in Newfoundland and Labrador is currently managed under a three-year integrated fisheries management plan. The 2006-2008 Snow Crab Integrated Management Plan is being reviewed and revised for 2009-2011. If management plan objectives are to be met, that is, conservation and sustainability, it is imperative that industry and management appropriately respond during this crucial time.

The precautionary approach for crab management needs to be taken into consideration more than ever with increasing pressure to increase TACs, continued fishing during soft-shell periods, increased incidences of bitter crab disease, and no adequate stock assessment for the species to ensure that mistakes made in the management of other fisheries, namely Atlantic cod (*Gadus morhua*), are not repeated. Instilling a conservation and stewardship ethic in fishers is also crucial to ensure the sustainability of the crab fishery with a resource for future fishers to harvest.

From another angle, with increasing awareness, consumers are demanding sustainable fisheries. Without such a designation, the Newfoundland and Labrador snow crab fishery could be in danger of collapse, despite the resource status, as markets will not purchase the resource from fisheries that are not sustainable.

In conclusion, the benefits of escape mechanisms have been discussed in detail above. Although it is difficult to put a value on a sustainably managed fishery, market based incentives in the future may very well be the impetus for change. However, the negligible cost of installing escape mechanism in crab pots at this point in time certainly has benefits for the future of the snow crab fishery and merits policy review.

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