Review of Ghost-Fishing; Scientific Approaches to Evaluation and Solution

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Ghost fishing refers that derelict fishing gear either lost or abandoned remains their capture function in water and continue inducing mortality of aquatic organisms without human control. It first became known among capture fishery scientists during the mid 1970's.[1, 2] It has become such an influential issue in the late 1980's as the closure of the high-sea drift-net fishery was attributed to, in part, the possibility of this problem.[3, 4, 5] Few scientific evidences were, however, presented those days. A large gap between less scientific evidences and its popularity is one of the characteristics of the ghost fishing issue even today.

The 1995 FAO Code of Conduct for Responsible Fisheries [6] seems to assume ghost fishing to be one of the most seriously negative impacts in the present capture fishery in par with less-selective fishing, bycatch/discards and destruction of habitats. The Code repeatedly urges prevention of fishing gear loss and technical improvement against ghost fishing. However, researches on ghost fishing, particularly quantitative approaches to the mortality assessment, are scarce and its impacts to aquatic resources have not been clarified. This paper reviews the researches on the evidences to prove ghost fishing, ghost fishing by a variation of fishing gear, the methodology for estimation of ghost-fishing mortality, development of technical countermeasures and the effects other than ghost fishing by derelict fishing gear.

1. DEVELOPMENT OF RESEARCHES ON GHOST FISHING

The ghost fishing study does not have a long history, in which the previous researches are categorised as:

(1) Surveys to obtain scientific evidences of ghost fishing,
(2) Assessment of ghost fishing mortality and its impacts, and
(3) Technical and experimental development of countermeasures to prevent ghost fishing and retrieval of lost fishing gear.

This review follows the above subjects and summarises the achievement by the previous researches. Due to the technical and verifiable approaches to derelict fishing gear and ghost fishing, this paper excludes most articles which only described this issue with no original data, while including the authors' unpublished information from part to part.

2. SCIENTIFIC EVIDENCES OF GHOST FISHING

Derelict fishing gear and ghost-fishing gear are different. Ghost-fishing was defined as 'the ability of fishing gear to continue fishing after all control of that gear is lost by the fisherman'.[7] The concept of mortality of organisms was not clear in this definition. This could be the factor which confused the following orientation of the researches. Presences of lost fishing gear in a fishing ground or contacts by fishes, *e.g.* entry of organisms in traps, are not adequate evidences to prove ghost fishing. Dead bodies and their species must be identified. From this viewpoint, there are a small number of researches which confirmed ghost fishing on the basis of monitoring of commercial or experimental fishing gear.

According to the author's underwater surveys mainly in Kyushu Island, Japan,[8] derelict gillnets, trammel-nets, small-scale Danish seine, bottom longlines, cage traps and pots were found, however, ghost fishing of finfishes or other fishery resource animals only by cage traps, gillnets and trammel-nets, small seine nets made of thin-twine net webbing was confirmed. Various traps of structures similar to the cages and net fishing gear which are made of net webbing similar to those of gillnets have possibilities of ghost fishing. This generalisation should be applicable in most cases over the world. Authors found no derelict gear other than bottom longlines around coral reefs in coastal waters in the Philippines (unpublished). Filipino coastal fishermen avoid gillnetting around coral reefs and retrieve nets by diving when they are lost. This is because gillnets are expensive assets for small-holder fishermen in developing countries. This suggests that the magnitude of the ghost fishing problems may depend on social and economic statuses of fishing sectors in each country.

2.1 Cage traps

Sheldon,[1] High,[2] Smolowitz [7, 9] and Pecci *et al.*[10] studied ghost fishing during the 1970's and those of crabs and lobsters by cage traps in the United Sates were confirmed. In particular, Pecci *et al.*[10] was the first quantitative research which reported ghost fishing efficiency and death rate in details. Ghost fishing was evidenced in the cage fisheries also for Dungeness crab in Canada [11] and finfishes in Kuwait.[12] On the other hand, there was such a study which reported numerous exits of the entered spiny lobster and slipper lobster and little direct morality in traps for them and consequently suggested that ghost fishing by those traps should not be a serious problem.[13] In the 1990's, ghost fishing of non-target species, such as the mortality of Tanner crab in lost traps for shellfish and cod [14] became concerned.[15]

Koike [16] introduced the ghost fishing issue in Japan in the early 1980's, however, no following study was conducted for a while in Japan. Matsuoka *et al.* conducted underwater observation of lost cage traps and their ghost fishing in a fishing ground where cage culture was also conducted.[8] It was revealed that traps were lost mainly because the float lines were tangled around the big mooring ropes for aquaculture cages and seabed rocks. Many commercial organisms such as leatherjacket, rockfish, red sea-bream, conger eel, octopus *etc.* were observed in the cages which remain the original structures. Fewer organisms were observed in the traps largely deformed due to breakage of frames, buried in sediment and covered by accumulated fouling organisms. These phenomena likely reflect the time elapsed since lost, therefore, the function of ghost fishing for traps was conjectured to decline along a time course, although very slow. The number of lost traps in the studied fishing ground was estimated to be 10 times more than those presently used by fishermen. It was important finding that the statistical distribution of the number of lost traps a unit area was represented by the Poisson's distribution. The observed average of the ratio of functioning traps was 0.43, although this value must depend on the rates of fishing gear loss and degradation that also depend on fishing gear and fishing ground conditions.

The organisms confined in traps demonstrated a variety of unusual behaviour such as bumping on net webbing inside, which they never show in the natural environment. The author has a hypothesis that the unusual behaviour is attributable to the high density and consequently stress in a trap for the animals which seldom meet in the natural fauna. The mortality induced by unusual behaviour and subsequent injury was clearly indicated by the relationship among the three phenomena observed in traps.[17] Such behaviour was, however, largely different from species to species. The contents of the digestion organs were analysed by Nagasawa *et al.* (unpublished) and few empty ones were found. This proves that entrapped fishes eat. Such a rumour that entrapped fish die due to starvation is denied.

Long-term observation indicated that cages in shallow waters can maintain the capture functions longer than 3 years. As described in the above, the ghost fishing function descends together with breakage and accumulation of fouling organisms. The former must be affected by the wave excitation force around the seabed and the latter, rich fauna of fouling organisms in shallow waters. Therefore, the capture function of lost gear is conjectured to last for a relatively short period of time in shallower waters. Deep-water traps which are less damaged by waves and less fouled biologically may continue ghost fishing longer than the above.

2.2 Gillnet and trammel-nets

In comparison to the early studies on ghost fishing by cage traps, studies on that by gillnets were relatively delayed. In the mid 1980's, remaining of lost gillnets in a fishing ground was first evidenced in Newfoundland, Canada [18] and ghost fishing by lost demersal gillnets was proved by surveys carried out with submersibles and an ROV in USA, although not quantitatively.[19] Several high-quality studies which observed ghost fishing of finfishes and crustaceans by lost bottom gillnets or trammel-nets under both natural and experimental conditions were conducted in USA,[20, 21] UK [22] and Portugal subsequently.[23]

According to Nakashima (in contribution), the consequences of lost bottom gillnets largely depend on the seabed circumstances on which nets are entangled. The capture function of gillnets lost on the flat bottom declined very rapidly together with the decreasing heights and increasing visibility due to fouling. Decline of gear heights was mainly attributed to debris on meshes and subsequent increase of hydrodynamic resistance and gradual stuck on small projections on seabed. The ghost-fishing mortality rate declined to 5% of the original catch efficiency at 142 days. It is noted that durations for which ghost fishing continues are different from species to species. The major ghost-fished species seem to be replaced during the time course since gear loss, as sub-demersal swimming species, *e.g.* sea-bream, are caught in the first several days and seabed dwellers, *e.g.* dragonet, for a longer period of time. Gillnets tangled around artificial reefs and rocky seabed three-dimensionally continued ghost fishing in a much greater extent of time.

Kaiser *et al.*,[22] Erzini *et al.*[23] and Nakashima and Matsuoka (in contribution) formulated the descending trend in mortality since loss of bottom gillnets. Integrations of the formulae up to the days when the gear efficiency declines to 5% of the original one gave the answers of duration of ghost fishing for 56~142 days and mortality of 318~455 animals a net (mainly finfishes and the values are different from those reported in the original papers). Although their net designs are different from each other, *i.e.* 2.1m~3.0m in height and 72m~100m in length and fishing grounds are also different, these values indicate the magnitude of ghost fishing impacts by lost bottom gillnets.

A gillnet which was tangled around an artificial reef experimentally, has been left longer than three years and so badly fouled as the netting monofilament is no longer visible maintains the ghost fishing mortality at the same level as the original. Since gillnets are easily tangled on three-dimensional structure such as artificial reefs, the above fact may provoke such a serious problem as the ghost fishing mortality of aggregated fish.

Ghost fishing of crabs and lobsters by so badly damaged gillnets or their fragments as the original structure no longer remains is frequently observed. This suggest that ghost fishing by lost gillnets continues perhaps longer for crustaceans.

3. METHODOLOGY OF ESTIMATION OF GHOST FISHING MORTALITY

Though most factors related to evaluation of ghost fishing mortality are unobservable in ambient and none of quantitative data appear in usual fishery statistics, the analytical model is similar to that for the usual fishing mortality estimation on the devoted fishing effort and CPUE.[17] On the basis of the following model, the researches required for quantitative evaluation of ghost fishing can be determined.

Ghost-fishing mortality, N_m of a species in a fishing sector in a fishing ground over a unit period of time is denoted as;

$$N_m = E_g \cdot m \quad \text{...... (1)}$$

where E_g is the number of ghost-fishing gear in a fishing ground and m, the ghost-fishing mortality rate per gear during a unit period of time.

The ghost-fishing mortality rate, m can be estimated mathematically on the basis of a probability model (Nakashima and Matsuoka, in contribution) with monitoring dead bodies of animals underwater or can be estimated as;

$$m = n_e \cdot k_m \quad \ldots\ldots (2)$$

where n_e is the number of effective contact (*e.g.* entering into traps) by a species to a gear in a unit period of time. The k_m is the death rate out of n_e, which could be a unit, or 1.0, *e.g.* in the case of gillnets, where n_e is assumed to be equivalent to m.

Since the ghost fishing function of lost fishing gear works continuously, the number of effective ghost-fishing gear E_g is corresponding to fishing effort in usual fishing activities. Derelict fishing gear is not necessarily ghost fishing gear, therefore, E_g is estimated as;

$$E_g = n_l \cdot r_e \cdot A \quad \ldots\ldots (3)$$

where n_l is the number of lost gear remaining in a unit area. The r_e is the average ratio of functioning gear of lost gear. The A is the total area of a ghost-fishing ground or where ghost-fishing gear is distributed.

It is not easy to quantify the n_l, r_e and A on the basis of *in situ* observation and sampling over a commercial fishing ground. It might be, therefore, a practical approach to estimate the number of ghost fishing gear in a certain sector with the number of operated fishing gear N_f and the annual gear loss rate R_l which are both obtained through interview for fishermen and the remaining duration t_f to maintain the ghost fishing function which must be experimentally obtained.

$$E_g = N_f \cdot R_l \cdot t_f \quad \ldots\ldots (4)$$

The method on which Breen [24] estimated the ghost fishing of Dungeness crabs in Canada with the estimated number of traps currently used, loss rate and mortality rate per trap is similar to the above approach. The estimation should be, however, not easy where the ghost fishing function declines slowly and it takes time for them to cease the entire function.

3.1 Researches on the parameters of ghost fishing mortality model

The early researches on the ghost fishing were oriented mainly to the parameters related to mortality m and those on the number of ghost fishing gear E_g were delayed. This difference was attributable to that even the former type of researches could prove ghost fishing qualitatively, however, those of the latter category were needed only for quantitative assessment of ghost fishing mortality.

Ghost fishing mortality *m*: The findings by Pecci *et al.*[10] that the ghost fishing mortality of a lobster for an inshore-type lobster trap was 13% of the original CPUE and the death rate for the entrapped population of lobster was 25% were presentation of m and k_m of the above model. A variety of values of k_m such as 50% for a Dungeness crab trap,[11] 45% for a blue crab trap,[25] 39% for Tanner crab to be caught by groundfish pots,[14] 86% and 7% for two species of crabs to be caught by crab pots [25] and 44% for octopus and less than 8% for finfishes to be caught by a fish trap [17] have been reported. The k_m value changes with time, therefore, the reported values are only averages. It must be clearly indicated in any researches if they are averages over either lost fishing gear or ghost fishing gear, however, it is sometimes not reported. No indication of the definitions is a fatal fault which confuses lost fishing gear and ghost fishing gear. Most of the above researches experimentally simulated the traps right after their losses. Therefore, they naturally dealt the latter, however, it may not be equal to the averages of ghost fishing traps of a variety of degradation conditions. There is no report of the k_m value for gillnets. This is attributable to the assumption of the entire kill of the enmeshed population.

There are also some researches which directly obtained the mortality m a gear and a unit period of time experimentally.[10, 25, 26] However, it must be noted that m also changes according to the time after loss.[17] This is supported by the finding that the number of entrapment n_e in the lost Tanner crab pots of two years old declined to 1/7 in comparison to those of one year old, although mortality was not confirmed.[27] It was also reported that the mortality m or catch changed more complicatedly together with seasons, elapsed time, and associated species.[26-28] Most experiments to find m were conducted with test animals which were initially put in a gear by researchers for subsequent monitoring, however, this method is applicable to only animals which are sufficiently resistant to stress and less damaged by handling. In the case of gillnets, Erzini *et al.* reported directly such a value as 314 to 221 animals within 17 weeks, while the m for gillnets declines with the elapsed time and is inconstant.[23] The ghost fishing function or the mortality per a unit period of time for lost gillnets declines together with increasing visibility and decreasing height, subsequently, the effective area of a net.[21, 22, 23] Authors found that declining of the ghost fishing function of bottom gillnets depends on seabed conditions where the nets are tangled.

The ghost fishing mortality rate m, including both k_m and n_e, changes in a time course, [10] therefore, an average value is used. Due to this fact, the gear efficiency values obtained from fishing gear properly used by fishermen are not applicable to approximate m. They must be evaluated on the basis of observation of lost gear. On the other hand, because of very short period of observable time for dead bodies of fishes,[17] usage of the direct number of observations of dead bodies falls in under-evaluation of m.

The number of ghost fishing gear E_g: The number of ghost fishing gear E_g was not studied in the early history of the ghost fishing studies. The number of lost fishing gear n_l in a unit area of a fishing ground became to be studied in the late 1990's, as surveys of the crab pot fishery in Alaska conducted with submersibles, a side-scan sonar and a ROV [27, 29] and scuba-diving survey of a finfish trap fishery in Japan.[8] There are a very small number of studies which dealt the ratio of the functional lost gear r_e and the area of ghost fishing ground A, with an exception of those by Matsuoka.[17]

The reason of limited studies in this field is not only the new need in the research history but also that underwater survey of E_g is not easy and time and effort consuming. The number of lost gear remaining in a unit area n_l is estimated on the basis of underwater observation of a statistically reliable area of a ghost-fishing ground, where the finding of Poisson's distribution of the numbers of lost fishing gear in a unit area can be utilised for methodological rationalisation. The total area of a ghost-fishing ground *A* was simply estimated on the basis of the current fishing ground and factors related to gear loss such as bottom conditions in the research by Matsuoka.[17] and this is one of the weakest aspects of ghost fishing studies.

Duration remaining capture function: There are several researches on the duration t_f for lost fishing gear to remain the capture function. Breen [11] clarified in the mid 1980's that lost traps for Dungeness crab retain the capacity to fish for a considerable time and there are reports of continuous catch of crustaceans by traps for longer than one or more years even though the efficiency declined.[26, 27] Matsuoka *et al.* found some fish traps even in a shallow-water continued ghost fishing for as long as five years sometime.[8] The duration of ghost fishing by lost gillnets depends of the seabed structure where they are tangled, while there are such reports as continuation longer than 9 months [22] and disappearance after 8 to 11 months.[22] Nakashima (unpublished) as described earlier found the catch efficiency declined to 5% of that of the original within several months in the case of flat seabed while those tangled around an artificial reef maintained almost the original catch rate after three years. The reason why there are quite active researches on the duration t_f to remain the ghost fishing function is that the value is applicable to estimate the number of ghost fishing gear E_g with Equation (4) for the alternative method in the above, no matter if it is intended or not.

Other problems: The above model is applicable only for the cases where ghost fishing occurs over a certain level of magnitude and the five factors can be quantitatively assessed from field surveys. Where the ghost fishing gear distribution density n_l and/or death rate k_m (or *m* itself) are low, quantitative estimation of mortality is not easy. It is noted that the ghost-fishing efficiency changes very rapidly right after gear loss sometime, *e.g.* gillnets at flat seabed, therefore the time lag of monitoring must be carefully decided. Monitoring of a simply constant time lag may fall in underestimation of the mortality rate *m*.

The researches so far do not take the mortality of organisms dislocated from ghost fishing gear after once contact. Unharvested injury and mortality in the even usual capture process have not been well studied and this issue in ghost fishing is totally beyond the range of the present study.

3.2 Case study of application of the model and quantitative estimation

The proposed method was applied to a case study.[17] Monitoring an accumulated total of 123 fish traps underwater in a coastal fishing ground of a municipal in southern Japan, the number of entries of each species a trap a year, the death rate among entries and, consequently, the number of mortality per gear were estimated, where *m* was 69 per gear a year for octopus. On the other hand, the ghost-fishing ground area was estimated to be 2,390,000m^2. The average number of lost traps, n_l per 100m^2 was 0.31. The average ratio of functional traps was 0.43. Applying these values, a total of 3,200 ghost-fishing traps, E_g was estimated over the municipal fishing ground.

The ghost fishing of octopus was most serious and the mortality of 212,000 to 505,000 individuals a year in the fishing ground was estimated. Though weight of the dead octopus was unknown due to the experiment with no handling the gear and animals (in order to avoid even a slight stress to animals, which may cause unusual behaviour, injury and mortality as stated earlier), assuming the similarity in size of octopus of both died in traps and landed by the local fishermen, the mortality was estimated as 100 to 250 tons. This was roughly equivalent to or twice greater than annual landing in the studied municipal, and suggests that ghost fishing likely affects resources at a noticeable level. A number of ghost fishing has been observed also for rock fish, conger eel, cuttlefish and other species, on the other hand, mortality of some entrapped fishes such as leatherjacket, red sea-bream, pennant coralfish, rainbowfishes and other reef species may be minimal.

As the above, comparison of the ghost fishing mortality to the normal landing amount in the fishing sector where the original gear is used easily depicts the magnitude of ghost fishing.

4. Other impacts by derelict fishing gear

Ghost fishing is merely one aspect of a variety of possible impacts by derelict fishing gear. Incidental catch of non-fishery animals [30] such as marine mammals [31-36] and reptiles, [37] and seabirds, [38] accumulation on seabed including entanglement on coral reefs, [33, 35, 39, 40] and contamination on the beach [33, 35, 41] have been reported. In addition to these biological and ecological impacts, navigation hazard is also discussed. Some people mention even possibly positive aspect such as aggregation of fish by derelict fishing gear on seabed.

It is easily observed that lost and aged cages are covered by algae and a variety of organisms and are hardly distinguished from rocks on seabed. They likely have the micro-FAD effects to aggregate fish. Sank aquaculture cages and large fishing gear such as seine nets form a composition of small spaces inside and likely support spawning and protect juveniles (Nakashima, unpublished). This has not been proved yet. It is noted that the nature of those aggregations must be scientifically assessed, because the newly formed fish community might be different from the natural ones.

Gillnets entangled on artificial reefs apparently increase fish aggregation efficiency (Nakashima, unpublished), however, this is not necessarily a positive aspect. This phenomenon kills the aggregated fish and, therefore, may accelerate ghost fishing. Lost traps and gillnets are also self-baited by the dead bodies of the ghost-fished animals and this may also accelerate their ghost fishing.[22, 27]

The authors have observed such deformation of seabed as the spaces around rocks are buried with sediment and changed to flat bottoms when rock reefs are covered by lost nets. A possible hypothesis is that the regional flow around nets is decelerated due to accumulation of fouling organisms on meshes, and consequently, deposition occurs. This may simplify the seabed environment and reduce biodiversity, however, it has not been evidenced yet. This is, on the other hand, also the process of burial of lost fishing gear in the seabed sediment and termination of ghost fishing. It is yet unknown if this process is irreversible.

In the 1980's, it became known that even fragments of lost fishing gear which no more remain the original capture functions cause mortality of a variety of wild life.[30-38] This has been criticised from the view point of conservation of wild life and environment. The mortality of marine mammals killed by fragments of derelict nets is one of the most famous examples. Recently it was documented that approximately 1.5-2% of Australian fur seals in Bass Strait and off southern Tasmania were found with entangled fragments of trawl nets which are known as neck collars [32] and it was evidenced by a number of field observations that Monk seals in Hawaiian Islands were found with entanglement of derelict nets.[33-35] It was also reported that sea turtles are peculiarly prone to tangle themselves in derelict lines and netting and are killed.[37] Entanglement of seabirds by lost monofilament lines has been photographed and documented in a variety of occasions, however, such impacts by commercial longlines have not been scientifically reported yet. This effect may be peripheral because the commercial bottom longline gear is composed of relatively thicker monofilaments and lost longlines are usually extendedly hung around reefs (Matsuoka and Nakashima, unpublished).

It was reported that water-birds may ingest lost or discarded lead fishing weights and poisoned.[42] Lead sinkers up to 200 tons per year lost in salmon fishing in Sweden are dissolved very slowly at approximately 1% a year.[43] One of the most serious concerns today is marine debris which is the derelict fishing gear drifting and widely spreading over the ocean. Derelict fishing gear entangled on, in particular, coral reefs are hardly recoverable due to possible destruction of corals. These may cause irreversible destruction of marine environment and magnify the problems of ghost fishing and entanglement of marine mammals.[34, 36] Derelict gear piled up in Hawaii and the other Pacific islands are mainly trawl nets [36] which are not locally used and assumed to be of a foreign origin. Identification of their original countries is a global concern, because when derelict gear is swept away from the original fishing grounds as the above the problems cannot be solved by the people of the damaged areas and may provoke external conflicts.

5. Countermeasures

Laista listed such countermeasures against ghost fishing as time-sensitive gear disabling mechanisms, disposal services for used fishing gear, technical developing to minimize gear loss.[15] Jones urged such countermeasures as education programmes, development of plastic-free gear, and clean-up programmes,[33] however, these are biased to marine debris reduction. The authors propose that the countermeasures against ghost fishing are prioritised in three aspects as; (1) prevention of fishing gear loss, (2) retrieval or dysfunction of lost gear, and (3) development of designed degradation of fishing gear when lost.

5.1 Prevention of fishing gear loss

Prevention of gear loss is the most fundamental solution against ghost fishing. The reasons of fishing gear loss are; (1) entanglement of gear or its accessory parts around seabed to unable hauling, (2) cut of float line due to interaction with other fishing gear, (3) misallocation during operations, and (4) drop of fishing gear either accidentally or intentionally.

Entangling of gear on rocks and reefs are avoidable in a certain extent by technical improvement of fishing gear and methods. The true reason of gear loss is, however, that fishermen choose fishing grounds, taking a risk of gear loss into account, in particular, when fishing gear is relatively inexpensive. On the other hand, it is also a fact that usual fishermen tend to avoid such fishing grounds. The situation can be improved by increasing public awareness of the long-term impacts to the resources by ghost fishing.

It is extensively observed that small fishing gear is broken by larger gear and cut off, where multiple types of fishing gear are used in the same fishing ground. The breakage of float lines by mooring ropes of aquaculture cages as described earlier is a typical example.[8] Cut of float lines by boats is a similar case, where fishing and navigation areas are over up. It must be noted in the coastal development and management strategy that the above-mentioned problems may be intensified where a variety of human activities are over-upped and multiple utilisation of coastal fishing grounds are encouraged.

The possibilities of the phenomena of the categories (3) and (4) above for fishermen equipped with high fishing technology such as DGPS may be minimal, however, it is widely observed that nets and traps are set with submerged markers in order to avoid from theft and naturally misplaced by fishermen themselves in developing countries. Therefore, education and promotion of social welfare are important factors to back-up the promotion of proper fishing.

It is an international trend to reduce fishing gear loss systematically by letting fishermen have their gear tagged to identify the users [6, 44] and developing disposal services to collect used fishing gear.[15] The most important countermeasures must be, therefore, the technical improvement and rationalised management of multi-sector fishing in coastal fishing grounds to avoid fishing gear loss first of all. The countermeasure must be taken into consideration in the overall coastal zone development and management policy.

5.2 Retrieval or dysfunction of lost fishing gear

Retrieval of lost fishing gear is tried in a variety of fashions. Iron clasps are widely used for this purpose, however, it is suggested that further damages to the seabed may be provoked by retrieval gear. Voluntary cleaning of seabed and dysfunctioning of lost fishing gear are conducted in shallow waters.[45] It is educationally effective, however, it is hardly a practical and essential solution due to high cost to efficiency. According to the authors' experiences, lost fishing gear is distributed over thorny bottom environment, where systematic retrieval seems practically difficult.

5.3 Designed degradation of ghost fishing gear

Techniques for rapid degradation of lost fishing gear or their parts have been tested since the early stage of the ghost fishing research. Attachment of time-releasable escape gap to a trap which opens after immersion for a certain period of time is a typical example.[12, 46] The technique is well developed now as the time required to dysfunction since lost is controllable and is already of practical application in fishery regulations in some countries.[14, 27, 47-50] Usage of such electro- and bio-degradable materials to net webbing and rigging of parts, *e.g.* floats of gillnets, are also being tested extensively.[20, 30] These techniques are particularly successful for traps, perhaps because the ghost fishing function of trap cages continue for a long period of time and there is an allowable time to reduce it. Usage of degradable materials must be, however, carefully evaluated taking the fact into account that ghost fishing is the most serious immediately after gear loss for example in the case of gillnets.

5. FUTURE STUDIES

On the basis of the above review, the sub-fields to be strengthened in the future researches on derelict fishing gear and ghost fishing are summarised as follows;

(1) Case studies of gear loss and the mechanism to induce ghost fishing, if any, for those other than gillnets and traps,
(2) Change in the ghost fishing function since lost,
(3) Quantitative assessment of ghost fishing mortality,
(4) Extensive survey and assessment of distribution of ghost fishing gear in wide areas, and
(5) Impacts to resources and environment other than ghost fishing by derelict fishing gear.

The most important but less studied area is the reason of fishing gear loss and its technical and legislative countermeasures. Fishing gear loss is an economic loss to business viability for fishermen and a negative impact to sustainability of the capture fishery sector. Therefore, countermeasures after gear loss must be an alternative way. Prevention of fishing gear loss is the most fundamental countermeasure, therefore, researches towards the following countermeasures are essential:

(1) Management of duplicated utilisation of fishing grounds by multiple fishing sub-sectors including aquaculture; and
(2) Improvement of fishing gear and methods when they are used in fishing grounds where gear loss easily occurs.

Although the overall impacts by derelict fishing gear and ghost fishing have not been assessed yet, it is convincing that the issue is no more simply a rumour or at a peripheral level. The challenge to assess and to reduce the problem must secure the future of the capture fishery because the resources currently wasted by ghost fishing could be converted to new resources additional to human consumption.

REFFERENCES

1. Sheldon WW. Trap contribution of losses in the American lobster fishery. *Fish. Bull.* 1975; **73**: 449-451.
2. High WL. Escape of Dungeness crabs from pots. *Mar. Fish. Rev.* 1976; **38**: 19-23.
3. Anon. Report of the Expert Consultation on Large-Scale Pelagic Driftnet Fishing, FAO, Rome, 1990. Page
4. Wright A, Doulman DJ. Drift-net fishing in the South Pacific: from controversy to management, *Mar. Policy* 1991; **15**: 303-337.
5. Richards AH. Problems of drift-net fisheries in the South Pacific. *Mar. Pollut. Bull.* 1994; **29**: 106-111.
6. Anon. Code of Conduct for Responsible Fisheries, FAO, Rome. 1995.
7. Smolowitz RJ. Trap design and ghost fishing: an overview. *Mar. Fish. Rev.* 1978; **40**: 2-8.
8. Matsuoka T, Osako T, Miyagi M. Underwater observation and assessment on ghost fishing by lost fish-traps. In: Zhou Y *et al.* (eds). *Fourth Asian Fish. Forum,* Beijing. 1997; 179-183.
9. Smolowitz RJ. Trap design and ghost fishing: discussion. *Mar. Fish. Rev.* 1978; **40**: 59-67.
10. Pecci KJ, Cooper RA, Newell CD, Clifford RA, Smolowitz RJ. Ghost fishing of vented and unvented lobster, *Homarus americanus*, traps. *Mar. Fish. Rev.* 1978; **40**: 9-43.
11. Breen PA. Ghost fishing by Dungeness crab traps: A preliminary report. *Can. Manuscr. Rep. Fish. Aquat. Sci.* 1985; **1848**: 51-55.
12. Mathews CP, Gouda VR, Riad WT, Dashti J. Pilot study for the design of a long life fish trap (gargoor) for Kuwait's fisheries. *Kuwait Bull. Mar. Sci.* 1987; **9**: 221-234.
13. Parrish FA, Kazama TK. Evaluation of ghost fishing in the Hawaiian lobster fishery. *Fish. Bull.* 1992; **90** (4): 720-725.
14. Kimker A. Tanner crab survival in closed pots. *Alaska Fish. Res. Bull.* 1994; **1** (2): 179-183.
15. Laist DW. Marine debris entanglement and ghost fishing: A cryptic and significant type of bycatch?. In: Wray T (ed.) *Proc. Solving Bycatch Workshop,* Seattle. 1996: 33-40.
16. Koike A. Pot structure and the catch, In: *Pot Fishery,* Koseishakoseikaku, Tokyo. 1981; 51-65.
17. Matsuoka T. Ghost-fishing by lost fish-traps in Azuma-cho water, *Mini Rev. and Data File Fish. Res.* 1999; **8**: 64-69.
18. Barney W. Lost gillnet retrieval project. 1983-1984. Department of Fisheries and Oceans, St. John's, 1985.

19. Carr HA. and Cooper RA. Manned submersible and ROV assessment of ghost gillnets in the Gulf of Maine. *Proc. Oceans'87. Ocean An International Workplace* **l** (2). 1987. 622-624.
20. Carr HA, Blott A. A study of ghost gillnets in the inshore waters of southern New England. *Proc. the Fish. Conservation Engineering Workshop.* 1991. 2-5.
21. Carr HA, Blott AJ, Caruso PG. A study of ghost gillnets in the inshore waters of southern New England. In: *Proc. Global Ocean Partnership*, Marine Technology Soc., Washington DC. 1992. 361-367.
22. Kaiser MJ, Bullimore B, Newman P, Lock K, Gilbert S. Catches in 'ghost fishing' set nets. *Mar. Ecol. Prog. Ser.* 1996; **145**: 11-16.
23. Erzini K, Monteiro CC, Ribeiro J, Santos MN, Gaspar M, Monteiro P, Borges TC. An experimental study of gill net and trammel net 'ghost fishing' off the Algarve (southern Portugal). *Mar. Ecol. Prog. Ser.* 1997; **147**: 257-265.
24. Breen PA. Mortality of Dungeness crabs caused by lost traps in the Fraser River Estuary, British Columbia. N. Am. J. Fish. Manage. 1987: 7; 429-435.
25. Guillory V. Ghost fishing by blue crab traps. *N. Am. J. Fish. Manage.* 1993; **13** (3): 459-466.
26. Bullimore BA. Newman PB. Kaiser MJ. Gilbert SE. Lock KM. A study of catches in a fleet of "ghost fishing" pots. *Fish. Bull.* 2001; **99** (2): 247-253.
27. Stevens BG, Vining I, Byersdorfer S, Donaldson WT. Ghost fishing by Tanner crab (*Chionoecetes bairdi*) pots off Kodiak, Alaska: pot density and catch per trap as determined from sidescan sonar and pot recovery data. *Fish. Bull.* 2000; **98** (2): 389-399.
28. Vienneau R, Moriyasu M. Study of the impact of ghost fishing on snow crab, *Chionoecetes opilio*, by conventional conical traps. *Can. Tech. Rep. Fish. Aquat. Sci.* 1994; 1984: 13.
29. Stevens BG. Crab bycatch in pot fisheries: Causes and solutions. In: Wray T. (ed.). *Proc. Solving Bycatch Workshop.* Seattle. 1996; 151-158.
30. Coleman FC, Wehle DHS. Caught by accident: The fishermen's unwanted harvest. *Oceans.* 1983; **16**: 65-69.
31. Henderson JR. Encounters of Hawaiian monk seals with fishing gear at Lisianski Island, 1982. *Mar. Fish. Rev.* 1984; **46** (3): 59-61.
32. Jones MM. Fishing debris in the Australian marine environment. *Mar. Pollut. Bull.* 1995; **30** (1): 25-33.
33. Donohue MJ, Brainard R, Parke M, Foley D. Mitigation of environmental impacts of derelict fishing gear through debris removal and environmental monitoring, In: *International Marine Debris Conference*, Honolulu. 2000; 58-78.
34. Henderson JR. A Pre- and Post-MARPOL Annex V Summary of Hawaiian Monk Seal Entanglements and Marine Debris Accumulation in the Northwestern Hawaiian Islands, 1982-1998. *Mar. Pollut. Bull.* 2001; **42** (7): 584-589.
35. Donohue MJ, Boland RC, Sramek CM, Antonelis GA. Derelict fishing gear in the Northwestern Hawaiian Islands: Diving Surveys and Debris Removal in 1999 Confirm Threat to Coral Reef Ecosystem. *Mar. Pollut. Bull.* 2001; **42** (12): 1301-1312.
36. Stewart BS, Yochem PK. Entanglement of pinnipeds in synthetic debris and fishing net and line fragments at San Nicolas and San Miguel Island, California, 1978-1986.

Marine Pollution Bulletin 1987; **18**: 336-339.
37. Carr A. Impact of nondegradable marine debris on the ecology and survival outlook of sea turtles. In: Wolfe DA. (ed.) *Sixth International Ocean Disposal Symp.* 1987; **18** (6B): 352-356.
38. Degange AR, Newby TC. Mortality of seabirds and fish in a lost salmon driftnet. Marine Pollution Bulletin 1980; **11**: 322-323.
39. Sutherland DL, Beardsley GL, Jones RS. Results of a survey of the south-Florida fish-trap fishing grounds using a manned submersible. Northeast Gulf Science 1983; **6**: 179-183.
40. Galgani F, Souplet A, Cadiou Y. Accumulation of debris on the deep floor off the French Mediterranean coast. Marine Ecology progress series 1996; **142**: 225-234.
41. Slip DJ, Burton HRⅣ. Accumulation of fishing debris, plastic litter, and other artifacts, on Heard and Macquarie Islands in the southern ocean. Environment Conservation 1991; **18**: 249-254.
42. Franson JC, Hansen SP, Duerr AE, Destefano S. Size and Mass of Grit in Gizzards of Sandhill Cranes, Tundra Swans, and Mute Swans. Waterbirds 2001; **2**: 242-244.
43. Jacks G., Bystroem M, Johansson L. Lead emissions from lost fishing sinkers. *Boreal Environ. Res.* 2001; **6** (3): 231-236.
44. Anon. FAO Technical Guidelines for Responsible Fisheries 1 – Fishing Operations, FAO, Rome. 1996.
45. Bech G. Retrieval of lost gillnets at Ilulissat Kangia. *NAFO Sci. Ccounc. Res. Doc.* 95/6. 1995.
46. Arcement E, Guillory V. Ghost fishing in vented and unvented blue crab traps. *Proc. LA. Acad. Sci.* 1993; **56** (1) 1-7.
47. Blott AJ. A preliminary study of timed release mechanisms for lobster trap. *Mar. Fish. Rev.* 1978; **40**: 44-49.
48. Fogarty MJ. The lobster fishery: Escape vents and bycatch issues。In: Castro K, Corey T, DeAlteris J, Gagnon C (eds.). *Proc. East Coast Bycatch Conference.* 1996; 63-64.
49. Blois S. The implementation of the galvanic time release mechanism on queen crab pots in the Gulf of St. Lawrence. A case of more responsible fishing. *Proc. MTS ' 92: Global Ocean Partnership.* Marine Technology Soc., Washington DC, 1992.
50. Selliah N, Oxenford H, Parker C. Selecting Biodegradable Fasteners and Testing the Effects of Escape Panels on Catch Rates of Fish Traps. In: Creswell RL (ed.), *Proc. Gulf Caribb. Fish. Inst.* 2001; **52**: 634-653.