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Review Article

A review of ghost fishing: scientific approaches to evaluation and solutions

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ABSTRACT: Research on ghost fishing became active in the late 1980s. Ghost fishing has been confirmed for traps, gillnets, trammel-nets and small seine nets. Some lost traps are functional for a long period of time, even in shallow waters. Consequences for gillnets after loss depend on seabed conditions. The ghost fishing function of gillnets remaining on flat seabeds declines rapidly with decreasing heights and increasing visibility. Gillnets left tangled around an artificial reef, for example, three-dimensionally maintain the initial magnitude of ghost fishing for a long period of time, even after badly fouled. There are increasing numbers of researches working on the total number of mortality per gear after gear loss for gillnets and trammel-nets. It has become also possible to estimate the total number of mortality for a unit period of time in a certain fishing sector. This paper reviews research which has provided evidence and quantitative data on ghost fishing, and proposes five items important for future studies on ghost fishing.

KEY WORDS: **artificial reef, ghost fishing, gillnets, lost gear, mortality, seine nets, trammel-nets, traps.**

INTRODUCTION

Ghost fishing refers to derelict fishing gear, either lost or abandoned, which continues to function in the water; continuing to induce mortality of aquatic organisms without human control (Fig. 1). It was first recognized among capture fishery scientists during the mid 1970s.[1,2] It became an influential issue in the late 1980s as the closure of the high sea large-scale drift net fisheries was attributed to, in part, the possibility of this problem.[3–5] Few scientific evidences were, however, presented in those days. A large gap between little scientific evidence and its popularity was one of the key points of the ghost-fishing issue.

The 1995 Food and Agriculture Organization of the United Nations (FAO) Code of Conduct for Responsible Fisheries[6] assumes ghost fishing to be one of the most seriously negative impacts in the present capture fishery industry; on par with less-selective fishing, bycatch/discards, destruction of habitats, and so forth. 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 on aquatic resources have been clarified little. This paper reviews the research evidence 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.

DEVELOPMENT OF RESEARCH ON GHOST FISHING

The study of ghost fishing does not have a long history. Previous research is categorized as: (i) surveys to obtain scientific evidence of ghost fishing; (ii) assessment of ghost-fishing mortality and its impacts; and (iii) technical and experimental development of countermeasures to prevent ghost fishing and to retrieve lost fishing gear.

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Fig. 1 Underwater photographs of ghost fishing by derelict cage trap and gillnet: (a) a dead body of an octopus in a lost cage trap for finfishes; (b) an injured rabbitfish which has lost its mouth and nose due to unusual behavior or repeated bumping on net webbing in a cage trap; (c) a lobster which is entangled on a lost gillnet which was tangled around rocks, heavily broken and badly fouled; (d) bones of finfishes scattered at the foot of an artificial reef which is covered by a gillnet. (a) and (c) were taken in fishing gear which were found by survey and (d) occurred around a gillnet experimentally set by the authors.

This review follows the above topics and summarizes the achievements by previous researches. Because of the intention of technical and verifiable approaches, this paper excludes most articles which only describe the issues of derelict fishing gear and ghost fishing with no original data, while including the authors' unpublished findings in field work from part to part.

SCIENTIFIC EVIDENCE OF GHOST FISHING

Derelict fishing gear is not necessarily ghost-fishing gear. 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. The presence of lost fishing gear in a fishing ground or contact by fishes, for example, entry of organisms in traps, are not adequate evidence to prove ghost fishing. Dead bodies and their species must be identified. There were a small number of early researches[2,8–14] which confirmed ghost fishing on the basis of monitoring of commercial or experimental fishing gear from the above viewpoint.

According to the authors' underwater surveys, mainly in Kyushu Island, Japan,[15] derelict gillnets, trammel-nets, small-scale Danish seines, bottom longlines, cage traps and octopus 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 cage traps and net fishing gear which are made of webbing similar to those of gillnets are possible for ghost fishing. This generalization should be applicable in most cases around the world. Authors found no derelict gear other than bottom longlines around coral reefs in a survey of coastal waters in the Philippines (T. Matsuoka, N. Nakashima and J. Ingles, unpubl. data, 1999). 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 the social and economic status of the fishing sector in each country.

Cage traps

Sheldon,[1] High,[2] Smolowitz[7,16] and Pecci *et al.*[8] studied ghost fishing during the 1970s, and those of crabs and lobsters by cage traps in the USA were confirmed. In particular, Pecci *et al.*[8] had the first quantitative research which reported ghost-fishing efficiency and the death rate in detail. Ghost fishing was evidenced also in a cage trap fishery in Canada for the Dungeness crab, where the ghost-fishing mortality was estimated to be equivalent to 7% of landing in the sector.[10] In contrast, there was such a study which reported numerous exits of the entered spiny lobster and slipper lobster and little direct mortality in traps in comparison to the total mortality of their population and consequently suggested that ghost fishing by those traps should not be a serious problem.[11] In the 1990s, ghost fishing of bycatch species, such as the mortality of Tanner crab in lost traps for shellfish and cod,[13] became a concern.[17]

Koike[18] introduced the ghost-fishing issue in Japan in the early 1980s, however, no following study was conducted for a while in Japan. After the mid 1990s, field surveys on ghost fishing by cage traps for finfishes[15,19] and red queen crab[20] (T. Watanabe, unpubl. data, 2002 & 2003) were also conducted in Japan. Matsuoka *et al.* carried out underwater observation of lost cage traps and their ghost fishing in a fishing ground where cage culture is conducted.[15] It was revealed that traps were lost mainly because the float lines were tangled around the large mooring ropes for aquaculture cages and seabed rocks. Many commercial organisms such as leatherjacket, rockfish, red seabream, conger eel, octopus etc. were observed in the traps which remain the original structures (Fig. 1a,b). 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 they were 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 639 which was 10-fold more than those presently used by fishermen a day, while a total number of 274 ghost-fishing traps was estimated. It was an important finding that the statistical distribution of the number of lost traps in a unit area of seabed was represented by Poisson's distribution. This finding is useful to rationalize the methodology of a field survey of derelict fishing gear. Because Poisson's distribution is determined by only one parameter (mean value), the sampling needs no procedure to find the variance. It is also a great benefit for the authors to carry out field surveys when finding up to a total of approximately 50 specimens is enough to secure an accurate reliable range, therefore, the number of sampling does not need to be taken into consideration. The ratio of ghost-fishing traps among the observed ones was 0.43, although this value is unique depending on the rates of fishing gear loss and degradation that also depends on fishing gear and fishing ground conditions.

The organisms confined in traps demonstrated a variety of unusual behavior, such as bumping on net webbing inside, which they never show in the natural environment. The authors have a hypothesis that the unusual behavior is attributable to the high density and consequent stress from being in a trap with other animals which seldom meet in the natural fauna. The mortality induced by unusual behavior and subsequent injury observed in the traps (Fig. 1b) was clearly indicated by the relationship among them.[19] Such behavior was, however, largely different from species to species. The contents of the digestion organs were analyzed (T. Matsuoka & N. Nagasawa, unpubl. data, 1998) 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 their capture function for sometimes longer than 3 years (T. Matsuoka & T. Nakashima, unpubl. data, 2002). As described 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 a lost trap is conjectured to last for a relatively short period of time in shallower waters. Watanabe suggested that lost traps have a long structural life under low temperature conditions (T. Watanabe, unpubl. data, 2002). Deep-water traps, which are also less damaged by waves and less fouled biologically, may continue ghost fishing for longer than the above.

Gillnet and trammel-nets

In comparison to the early studies on ghost fishing by cage traps, studies on gillnets were relatively delayed. In the mid 1980s, remaining lost gillnets in a fishing ground were first evidenced in Newfoundland, Canada,[21] and ghost fishing by lost demersal gillnets was proved by surveys carried out with submersibles and a remote operatable vehicle (ROV) in the USA, although not quantitatively.[22–25] Subsequently, several high-quality studies which observed ghost fishing of finfishes and crustaceans by lost bottom gillnets and trammel-nets under both natural and experimental conditions were conducted, and quantitative assessment of mortality was made in the UK,[26] Portugal,[27,28] Spain,[29] Norway[30] and Japan.[31,32]

According to Nakashima and Matsuoka,[32] consequences for lost bottom gillnets largely depend on the seabed circumstances where the nets remain. The capture function of gillnets lost on the flat bottom declined very rapidly together with the decreasing heights[33] and increasing visibility due to fouling. Decline of gear heights was mainly attributed to debris on meshes and the subsequent increase of hydrodynamic resistance and gradual stuck on small projections on the seabed. The ghost-fishing mortality rate declined to 5% of the original catch efficiency at 142 days.[31] 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 subdemersal swimming species, for example sea-bream, are caught in the first several days and seabed dwellers, for example dragonet, for a longer period of time.

Gillnets tangled around artificial reefs and rocky seabeds three-dimensionally continued ghost fishing to a much greater extent of time (Fig. 1c,d). Kaiser *et al.*,[26] Erzini *et al.*,[27] Santos *et al.*,[28] Sancho *et al.*,[29] and Nakashima and Matsuoka[31] 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%[31] of the original one, gave the answers of duration of ghost fishing for 30–328 days and mortality of 84–455 animals in the case of finfishes, while, 30–586 days and 4.4–1823 animals a net when including crustaceans and an extremely large-mesh gillnet (Table 1; the values are different from those in the original papers due to recalculation by the authors[31]). Recently, continuation of ghost fishing for a long period of time, such as no decline of mortality[32] or level off after initial decline of mortality,[30] are also reported, where ceasation of ghost fishing was not identified (Table 1). Although their net designs and fishing grounds are different from each other among the five researches, these values indicate the general trend of ghost-fishing impacts by lost bottom gillnets and trammel-nets.

A gillnet which was tangled around an artificial reef experimentally, and was left for longer than 3 years and was so badly fouled that the netting monofilament was no longer visible, maintained the ghost-fishing mortality at the same level as the original.[32] Revill and Dunlin[34] reported that gillnets tangle over wrecks maintain the stretched area of webbing *in situ* and ghost fishing continued for longer than 2 years. Since gillnets are easily tangled on three-dimensional structures such as artificial reefs, wrecked ships and large rocks, the above fact may provoke such a serious problem as the ghost-fishing mortality of aggregated fishes.

Such research is also conducted as the ages of gillnets since lost were estimated on the basis of the total amount of the accumulated fouling organisms.[35] Ghost fishing of crabs and lobsters by so badly damaged gillnets or even their fragments as the original structure no longer remains is frequently observed (Fig. 1c). This suggest that ghost fishing by lost gillnets continues perhaps longer to non-fish animals such as crustaceans.

METHODOLOGY OF ESTIMATION OF GHOST-FISHING MORTALITY

Although most factors related to the assessment 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 catch per unit effort (CPUE).[36] On the basis of the following model, the researches requirements 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:

$$N_m = E_g \cdot m \tag{1}$$

where, E_g is the number of ghost-fishing gear in a fishing ground and m is 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[32]) with monitoring dead bodies of animals underwater or can be estimated as:

Table 1 Reported number and duration of ghost-fishing mortality induced by derelict gillnets and trammel-nets

Authors	Year	Fishing gear	Net length (m)	Net hight (m)	Mesh size (mm)	Target organisms	Estimated mortality per gear (number)[†]	Duration to continue mortality (days)[†]	Country
Kaiser *et al.*[22]	1996	Gillnet	90	3	100	Fish	226 (334)	70 (141)	UK
						Crustaceans	839 (1823)	136 (586)	
		Trammel-net	90	2.7	100 (inner)	Fish	78 (321)	22 (328)	
					600 (outer)	Crustaceans	754 (567)	136 (78)	
Erzini *et al.*[23]	1997	Gillnet	100	2.1[‡]	60	Fish (included crustaceans)	344 (319)	120 (57)	Portugal
		Trammel-net	100	1.7[‡]	60 (innner) 110 (outer)	Fish (included crustaceans)	221 (267)	120 (148)	
Nakashima and Matsuoka[25]	2003	Gillnet	72	2.3	60 to 99	Fish	455	142	Japan
Sancho *et al.*[29]	2003	Gillnet	50	3.6	280	Fish	4.7 (4.4)[§]	224 (180)	Spain
Santos *et al.*[28]	2003	Gillnet	53	5.4	81	Fish	87.6 (84)[§]	248 (30)	Portugal
Humborstad *et al.*[30]	2003	Gillnet	27.5	5.1	180	Fish	(815–1217 kg)[¶,††]	365[‡‡]	Norway
						Fish	(341–523 kg)[¶,††]	365[§§]	
Nakashima and Matsuoka[24]	2005	Gillnet	16	2.3	67 to 90	Fish	191	365	Japan

[†]The values in the brackets are those recalculated by the authors on an asumption that the duration of ghost fishing is assumed to be the number of days until the day when the mortality declines to 5% of the initial value.
[‡]The net height was estimated on the hanging ratio of 0.5.
[§]The mortality was converted to that per 100-m long net.
[¶]The mortality was converted to that for one piece of net on the fact that 1 fleet = 30 nets.
[††]The mortality was converted to that in 1 year because no decline of ghost-fishing mortality was reported.
[‡‡]From the data in 2000.
[§§]From the data in 2001.

$$m = n_e \cdot k_m \tag{2}$$

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. k_m is the death rate out of n_e, which could be a unit, or 1.0, for example 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, corresponds to fishing effort in usual fishing activities. Derelict fishing gear is not necessarily ghost-fishing gear, therefore, E_g is estimated as:

$$E_g = n_l \cdot r_e \cdot A \tag{3}$$

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

It is not easy to quantify 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 or questionnaire to fishermen and the remaining duration, t_f, to maintain the ghost-fishing function which must be experimentally obtained.

$$E_g = N_f \cdot R_l \cdot t_f \tag{4}$$

The method on which Breen[10] estimated the ghost-fishing catch 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 of ghost-fishing mortality by Sancho[29] on a gillnet fishery for monkfish in Spain and Santos[28] on a gillnet for hake in Portugal are similar approaches. For this approach, it is the most important to find the time period to be taken to cease the entire ghost-fishing function for lost fishing gear. This is perhaps the reason why there has been much research recently to find the duration of ghost fishing and mortality during this period (Table 1).

Research on the parameters of the ghost-fishing mortality model

Early research[8,10,12–14] on ghost fishing were oriented mainly to the parameters related to mortality, m, and those on the numbers of ghost-fishing gear, E_g, were delayed.[19,37,38] This was attributable to the fact that even the former type of research 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.*[8] 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 on presentation of m and k_m of the above model. A variety of values of k_m such as 55%[10] for a Dungeness crab trap, 45% for a blue crab trap,[12] 39% for a Tanner crab to be caught by ground-fish pots,[13] 100% for both brown crab and lobster to be caught by crab pots,[38] 44% for octopus and less than 14% for finfishes to be caught by a fish trap,[19] 22% for lobsters by lobster trap[11] and 95% for snow crab by crab trap[39] have been reported. The k_m value changes with time, therefore, the reported values are only averages. It must be clearly indicated in any research whether 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 with 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, for gear and a unit period of time experimentally.[8,12,40] However, it must be noted that m also changes according to the time after gear loss.[19,41] This is supported by the finding that the number of entrapment, n_e, in the 2-year-old lost Tanner crab pots declined to 1/7 in comparison to those of the 1-year-olds, although mortality was not confirmed.[38] It was also reported that the mortality, m, or catch changed more complicatedly together with seasons, elapsed time, and associated species.[14,38,40] Most experiments[2,8,10–14,42] 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 only to 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 344 individuals of finfishes and crustaceans within 17 weeks, while the m for gillnets declined with the elapsed time and was inconstant.[27] The ghost-fishing function or the mortality per unit period of time for lost gillnets declines together with both/either increasing visibility and/or decreasing height, subsequently, the effective area of a net.[22,25–28,31,33,34,43] Revill and Dunlin and the authors found a declining ghost-fishing function of bottom gillnets depends on seabed conditions where the nets are lost.[32,34]

The ghost fishing mortality rate, m, including both k_m and n_e, changes in a time course,[8] therefore, an average value is used. Due to this fact, the catch rate values accessed for fishing gear properly used by fishermen are not applicable to approximate m. They must be evaluated on the basis of observation of lost gear. In contrast, because of the very short period of observable time for dead bodies of fishes,[19] usage of the direct number of observations of dead bodies to represent m may fall in its underevaluation.

The number of ghost-fishing gear, E_g

The number of ghost-fishing gear, E_g, was not dealt with in the early ghost-fishing studies.[22,23] The number of lost fishing gear, n_l, in a unit area of a fishing ground came to be studied in the late 1990s, as surveys of a crab-pot fishery by using side-scan sonar in Alaska[37,38] and a finfish-trap fishery by diving in Japan.[15,19] Recently, research to estimate the number of lost fishing gear in a fishing sector from interview or questioning of fishermen is increasing as discussed earlier.[10,28,44] There is very few research which has dealt with the ratio of the functional lost gear, r_e, and the area of ghost-fishing ground, A, with exception of research by Matsuoka.[19]

Limited studies in this field is not the only reason for the need for research history but also that underwater survey of E_g is not easy but 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 utilized for methodological rationalization. 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[19] and this is one of the weakest aspects of ghost-fishing studies.

Duration remaining capture function

There are several studies on the duration, t_f, for lost fishing gear that remain with a capture function. Breen[45] clarified, in the mid 1980s, that lost traps for Dungeness crab retain the ability to fish for a considerable time and there are reports of continuous catching of crustaceans by traps for longer than 1 or more years even though the efficiency declines.[38,40] Matsuoka *et al.* found some finfish traps even in shallow-water continued ghost fishing for as long as 3 years.[15] The duration of ghost fishing by lost gillnets depends on the seabed structure where they are tangled, while there are such reports of continuation for longer than nine months[26] and disappearance after 15–20 weeks.[27] Nakashima and Matsuoka[31] found the catch efficiency declined to 5% of that of the original gear in approximately 20 weeks in the case of flat seabed while those tangled around an artificial reef maintained almost the original catch rate after 3 years. The reason why there are quite active researches working on the duration, t_f, remaining with 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, n_e, k_m, n_l, r_e and A, 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, for example gillnets at a flat seabed, therefore, the time lag of monitoring must be carefully decided. Monitoring of a simply constant time lag may result in underestimation of the mortality rate, m.

The research so far does not take the mortality of organisms dislocated from ghost-fishing gear after first 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.

Case study of application of the model and quantitative estimation

The proposed method was applied to a case study as follows.[19] 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 in a trap in a year, the death rate among entries, and, consequently, the number of mortality per gear were estimated, where m was 69–168 per gear a year for octopus. The ghost fishing ground area, A, was estimated to be 2 390 000 m^2. The average number of lost traps, n_l, per 100 m^2 was 0.31. The ratio of functioning traps, r_e, was 0.43. Applying these values, a total of 3200 ghost-fishing traps, E_g, was estimated over the municipal fishing ground.

The ghost fishing of octopus was most serious and the mortality, N_m, of 212 000–505 000 individuals a year in the fishing ground was estimated. Although the weight of the dead octopus was unknown due to the experiment not handling the gear and animals (in order to avoid even slight stress to animals, which may cause unusual behavior, 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 roughly as 100–250 tons. This was approximately equivalent to or twice greater than annual landing in the municipal, and suggests that ghost fishing likely affects resources at a noticeable level. Ghost fishing has been observed also for rock fish, conger eel, cuttlefish and other species, however, mortality of some entrapped finfishes such as leatherjacket, red sea-bream, pennant coralfish, rainbowfishes and other reef species may be minimal.

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[46] such as marine mammals,[46–52] reptiles[53] and seabirds,[54] accumulation of fishing gear on seabed including entanglement on coral reefs,[49,50,55,56] and contamination on the beach[48,49,57] have been reported. In addition to these biological and ecological impacts, navigation hazard is also discussed in a series of International Marine Debris Conferences (S. Carroll, pers. comm., 2000). Some people mention even a possibly positive aspect such as aggregation of fish by derelict fishing gear on the 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 the seabed. They likely have the micro-fish aggregation device (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 (N. Nakashima & T. Matsuoka, unpubl. data, 2003). This has not yet been proved. 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 and Matsuoka[32]), however, this is not necessarily a positive aspect. This phenomenon kills the aggregated fish and 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.[26,38]

The authors have observed such deformation of seabeds as spaces around rocks being buried with sediment and conversions 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 yet been evidenced. This is, however, 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 or not.

In the 1980s, it became known that even fragments of lost fishing gear, which no longer has its original capture functions, cause mortality of a variety of wild life.[46–54] This has been criticised from the viewpoint of conservation of wild life and the environment. The mortality of marine mammals killed by fragments of nets is one of the most famous incidents. It was recently 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,[48] and it was evidenced by a number of field observations that Monk seals in the Hawaiian Islands were found with entanglement of derelict nets.[49–51] It was also reported that sea turtles are particularly prone to tangle themselves in derelict lines and netting and are thus killed.[53] 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 yet been scientifically reported. 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 (T. Matsuoka, N. Nakashima & J. Ingles, unpubl. data, 1999). It was reported that water-birds may ingest lost or discarded lead fishing weights and so be poisoned.[58] Up to 200 tons of lead sinkers are lost per year in salmon fishing in Sweden.[59]

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 the corals. These may cause irreversible destruction of the marine environment and magnify the problems of ghost fishing and entanglement of marine mammals.[49,50] Derelict gear drifted and piled up in Hawaii and the other Pacific islands are mainly trawl nets[50] which are not locally used and assumed to be of a foreign origin. Identification of the countries or region of their origin is a global concern, because when derelict gear is swept away from the original fishing grounds as per the above, the problems cannot be solved by the people of the damaged areas and may provoke external conflicts either internationally or domestically.

COUNTERMEASURES

Laist listed such countermeasures against ghost fishing as time-sensitive gear disabling mechanisms, disposal services for used fishing gear, and technical development to minimize gear loss.[17] Jones urged such countermeasures as education programmes, development of plastic-free gear, and clean-up programmes,[49] however, these are biased to marine debris reduction. The authors propose that the countermeasures against ghost fishing are prioritized in three aspects: (i) prevention of fishing gear loss; (ii) retrieval or dysfunction of lost gear; and (iii) development of designed degradation of fishing gear when lost.

Prevention of fishing gear loss

Prevention of gear loss is the most fundamental solution against ghost fishing. The reasons for fishing gear loss are: (i) entanglement of gear or its accessory parts around seabeds which prevents hauling; (ii) cut-off float line due to interaction with other fishing gear; (iii) misplacement during operations; and (iv) dropped fishing gear either accidentally or intentionally.

Entangling of gear on rocks and reefs are avoidable to a certain extent by the technical improvement of fishing gear and methods, for example wider usage of an intermediate float on the buoy line for bottom-set fishing gear. The true reason for gear loss, however, is that fishermen choose fishing grounds, taking a risk of gear loss into account, in particular, when fishing gear is relatively inexpensive. In contrast, it is also a fact that regular fishermen tend to avoid such fishing grounds. The situation can be improved by increasing public awareness of the long-term impacts to resources by ghost fishing.

It is extensively observed that small fishing gear is destructed 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.[15] Cut-off float lines by boats is a similar case, where fishing and navigation areas overlap. 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 overlapped and multiple utilization of coastal fishing grounds are encouraged.

The possibilities of the phenomena of misplacement of fishing gear during operations and dropped fishing gear 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 theft and naturally misplaced by fishermen themselves in developing countries. Therefore, education and promotion of moral and social welfare are important, particularly in deprived communities, to back-up the promotion of proper fishing. It is an international trend to reduce fishing gear loss systematically by having fishermen's gear tagged to identify the users[6,60] and by developing disposal services to collect used fishing gear.[17]

The most important countermeasures must be technical improvement, as discussed below, and rationalized management of multisector fishing in coastal fishing grounds to avoid fishing gear loss at all. The countermeasure must be taken into consideration in the overall coastal zone development and management policy. The authors observed a fishing community where an internal rule that static gear users are compensated by mobile gear users when gear loss has been established, however, such a system is still of little favour in Japan.

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 seabeds and dysfunctioning of lost fishing gear are conducted in shallow waters.[61] It is educationally effective, however, it is hardly a practical and essential solution due to the high cost of efficiency. According to the authors' experiences, lost fishing gear is distributed over thorny bottom environments, where systematic retrieval seems practically difficult.

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.[62]

There are a couple of experimental data to prove the effectiveness of this technique such as escapement of crabs entrapped in cages at as high as 99% in comparison to 0% for conventional cages[63] and that of sublegal size crabs at 80–99% by using degradable materials together with an escape gap.[37] The technique is well developed now as the time required to dysfunction since lost is controllable. It is already of practical application in fishery regulations in some countries,[13,38,64–67] however, quantitative assessment of the effectiveness of application of this technique in management is not easy. Usage of such electro- and bio-degradable materials to net webbing and rigging of parts, for example floats of gillnets, are also being tested extensively.[25,37] These techniques are particularly successful for traps, perhaps because the ghost-fishing function of cage traps continue for a long period of time and a technically allowable time to reduce it is long enough in comparison to the control of the time period needed for the degradation of parts. Usage of degradable materials must be, however, carefully evaluated, taking into account the fact that ghost fishing is most serious immediately after gear loss, for example only within a couple of days for some species in the case of gillnets.[31] In this kind of case, authors consider it not realistic to satisfy both intended degradation and required durability for fishing gear materials under a variety of environmental conditions.

FUTURE STUDIES

On the basis of the above review, the subfields to be strengthened in future research on evaluation of derelict fishing gear and ghost fishing are summarized 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 Clarification of change in the ghost-fishing function since gear loss;

3 Quantitative assessment of ghost-fishing mortality;

4 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 for 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 is an alternative way. Prevention of fishing gear loss is the most fundamental countermeasure and so research towards the following countermeasures are essential:

1 Management of duplicated utilization of fishing grounds by multiple fishing subsectors including aquaculture; and

2 Improvement of fishing gear and methods, considering those before and after loss, 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 yet been assessed, it is convincing that the issue is no more simply a rumour or at a peripheral level. The challenge to assess and reduce the problem must secure the future of the capture fishery industry because the resources currently wasted by ghost fishing could be converted to new resources additional to human consumption.

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