Keynote Speech

The Problem of Derelict Fishing Gear - Global Review and Proposals for Action

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The Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UNEP) are undertaking a study entitled *The Problem of Derelict Fishing Gear: Global Review and Proposals for Action*. The review is being undertaken as a consultancy by Steve Raaymakers of EcoStrategic Consultants and the interim draft report has recently been submitted. The review currently concludes, that *inter alia*:

- Derelict Fishing Gear (DFG) is a serious global marine environmental problem, causing significant ecological, biodiversity, economic and amenity impacts;

- Scientific data and information on the problem is highly geographically patchy, with relatively good data being available from a few concentrated geographical areas where intensive studies have been conducted, such as near the Hawaiian Islands, the Seas of North East Asia and the North Pacific generally; some limited studies being available from other areas such as around Australia and in European Seas, and many other regions having very little to absolutely no data at all;

- Much more has to be done to ensure that the artisanal, small scale and industrial fisheries
  sectors are addressed as well as DFG from IUU fishing

- Sound international policy, legislative and regulatory regimes have been developed and are in place on paper (e.g. MARPOL Annex V), however there are very serious in-adequacies with the implementation and enforcement of these regimes;

- Addressing the problem is challenging as it depends to a significant degree on changing human behaviour, rather than relatively straight-forward technological fixes;

- A concerted global effort is needed to begin to address the problem, involving close cooperation between the main relevant UN agencies (FAO, IMO, UNEP, IOC), Regional Fisheries Bodies, Regional Seas Organizations, Governments, the fishing industry, ports and environmental NGOs;

- This response should initially focus on:

  - a massive and sustained global awareness and outreach programme, targeting the fishing industry and ports as primary audiences, adopting innovative communication approaches designed to effect cultural shift and behavioural change, and implemented regionally (with programmes in each region being regionally-relevant and culturally appropriate),

- the undertaking of a global review of the total economic costs of DFG, to help in assessing the overall significance of the DFG problem, and because economic arguments are often most persuasive in human society,

- a programme to develop DFG trajectory models for each main regional sea of the world,

- a programme to develop innovative technological developments and gear improvements for each main fishery of the world, to prevent/reduce loss and abandonment of fishing gear at sea,

- a programme to develop innovative economic incentives and financial instruments for each main fishery of the world, to prevent/reduce loss and abandonment of fishing gear at sea, recognizing that such are often more effective than the threat of punitive penalties and punishments,

- a programme to undertake more detailed studies and monitoring in those regions of the World where very little to no data is currently available (e.g. seas around Africa, South Asia and South America),

- the establishment of central, global databases for the reporting of annual statistics by National Governments relating to:
    - maritime safety incidents caused by DFG.
    - entanglement of species of conservation concern.
    - the sources, causes, quantities and distribution of DFG, , including data from coastal survey and monitoring programmes.

  These databases could present outputs graphically on map-based Geographic Information System (GIS) - providing visual representation of the geographical spread of the problem. This would provide a powerful monitoring tool for assessing the true global extent of the problem, including regional hot spots, as well as trends over time and the effectiveness or otherwise of management and control responses.

- Engaging more strongly with relevant industry groups to secure their involvement and material support for DFG reduction activities, including the formation of cross-sectoral DFG Task Forces under the auspices of each RFB.

- The implementation of technical cooperation programmes to assist countries to *implement the existing international regime* relating to DFG, including MARPOL Annex V and the provision of adequate waste reception facilities in ports, as well as implementation of the FAO Code of Conduct on the Responsible Management of Fisheries, rather than developing new instruments, codes and other measures.

The global response should focus on implementing the existing regulatory regime, which in itself is a strong regime (if implemented), and not on developing new regimes (which would be a repetitive waste of scarce resources).

The Problem of Derelict Fishing Gear: *Global Review and Proposals for Action*

United Nations Environment Programme (UNEP)
Food & Agriculture Organization of the United Nations (FAO)
EcoStrategic Consultants

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Introduction & background

The problem of Derelict Fishing Gear (DFG)

- Major component of the broader marine litter issue
- Serious global marine environmental problem, causing significant impacts
- UN GA Res. A60 L22
- Action by UNEP and FAO

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Objectives of the Review

- Review and summarise available relevant information on the DFG issue globally, including:
  - sources, quantities and distribution
  - threats and impacts
  - existing global, regional and national responses to the issue
- Make proposals for further action at the global and regional levels, including for greater cooperation between the Regional Fisheries Bodies (RFBs) and Regional Seas Organizations (RSOs)
- Assess the need and feasibility of new legal instruments and/or associated guidelines to address DFG at regional and national levels.

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6 main impacts of DFG

1. Navigational safety – human life & property
2. Ghost fishing
3. Entanglement etc non-target species
4. Transfer invasive species
5. Beaching / coastal impacts
6. Economic impacts

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Sources, quantities and distribution

- Problem since 1960s – synthetic materials
- Two main sources are 'voluntary' and 'involuntary'
- Voluntary = intentional discard or abandonment
- Involuntary = accidental loss
- Weather and sea conditions
- Interactions between fisheries
- IUU fishing

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Sources, quantities and distribution

- Global data on quantities and distribution is very patchy
- Good data for North Pacific, Hawaiian Islands
- Some data for Europe and Australia
- Very little data from elsewhere
- ICC and similar coastal cleanups of limited value
- Distribution driven by ocean currents

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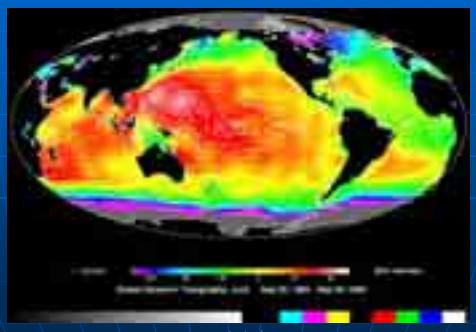
Generic global ocean currents

Ocean topography (TOPEX/Poseidon)



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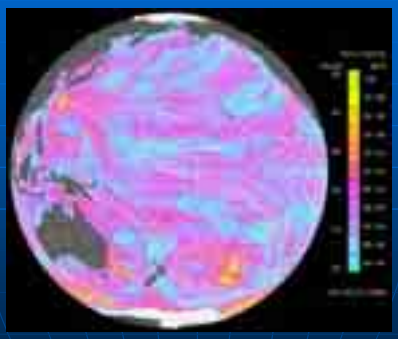
Surface Winds (QikSCAT)



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Regional current patterns

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Local-scale complexities

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Existing Actions

- IMO – MARPOL Annex V

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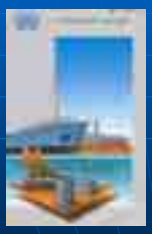
Existing Actions

- Port Waste Reception Facilities



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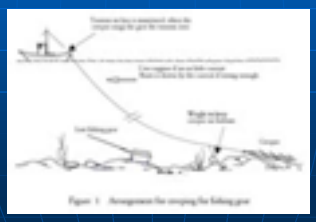
Existing Actions

- FAO Code of Conduct for Responsible Fisheries
- FAO work on Ghost Fishing and Gear Marking



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Existing Actions

- UNEP Global Marine Litter Partnership
- UNEP Regional Seas Regional Marine Litter Actions
- UNEP / FAO Global Review

Plus national / local actions, e.g.

- US NOAA Marine Debris program
- WWF Australia Nets ID Kit

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Proposals for Action

- Sound international policy, legislative and regulatory regimes are in place on paper (e.g. MARPOL Annex V, FAO Code of Conduct).
- Very serious in-adequacies with the implementation and enforcement of these regimes.
- Addressing the problem is challenging as it depends to a significant degree on changing human behaviour, rather than relatively straight-forward technological fixes.
- A concerted global effort is needed to begin to address the problem, involving close cooperation between the main relevant UN agencies (FAO, UNEP, IMO etc), Regional Fisheries Bodies, Regional Seas Organizations, Governments, the fishing industry, ports and environmental NGOs.

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Proposals for Action

The global response should initially focus on:

- A massive and sustained global awareness and outreach programme, targeting the fishing industry and ports as primary audiences, adopting innovative communication approaches designed to effect cultural shift and behavioural change, and implemented regionally (with programmes in each region being regionally-relevant and culturally appropriate),
- A programme to develop innovative technical and gear improvements as well as economic incentives and financial instruments to prevent/reduce loss and abandonment of fishing gear at sea (must be fishery specific),

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Proposals for Action

- More detailed studies and monitoring in those regions of the World where very little to no data is currently available (e.g. Seas around Africa, South Asia and South America).
- The development of DFG tragectory models for each main regional sea
- The establishment of a global DFG information system
- Closer linkages between RFBs and RSOs and between efforts to address DFG and marine litter generally
- Close involvement of the fishing, fishing gear, ports, waste management and other industries

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Regional Fisheries Bodies

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Proposals for Action

- The global response should focus on implementing the existing regulatory regime, which in itself is a strong regime (if implemented), and not on developing new regimes (which would be a repetitive waste of scarce resources).
- We already have the tools – we just need to use them
- To do this we need to "want to use them" (cultural change) and "know how to use them" (build capacity)

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'The problems of ocean space are closely interrelated and need to be considered as a whole . . . '
(UN General Assembly 1970)

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Special Lecture

Ghost-fishing impact by derelict fishing gear

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1. Introduction

Derelict fishing gear is one of the major sources of marine debris, which cause unique influences due to their structures and functions. There are a variety of impacts by derelict fishing gear, among which ghost fishing is the most serious one. Ghost fishing is defined as derelict fishing gear which left fishermen's control no matter if intentionally or accidentally and maintain its capture function continue inducing mortality of fishery organisms underwater. [1)] It was first recognised among fishery scientists, managers and environmentalists in the mid 1960's and early scientific studies were conducted in the 1970's. [1, 2, 3)] It became such an influential issue as the closure of the high sea drift-net fisheries in the late 1980's was attributed to, in part, the possibility of this problem. [4, 5, 6)] A number of intellectual researches have been conducted recently and the accurate figure of ghost fishing is becoming evident. This report reviews (1) the evidences to prove ghost fishing, (2) ghost fishing by fishing gear types, (3) the effects other than ghost fishing by derelict fishing gear, (4) the methodology for estimation of ghost-fishing mortality, and (5) development of technical countermeasures in order to provide a basis for discussion among the people concerned.

2. Researches on derelict fishing gear and ghost fishing

Various influences by derelict fishing gear: The impacts by derelict fishing gear are categorised into direct mortality of organisms and indirect ones bridged by declining environmental conditions. The direct influences include ghost fishing and incidental catch of non-fishery animals such as; marine mammals, marine reptiles and sea birds. Indirect ones are; accumulation of fishing gear on seabed and coral reef, contamination on beach, deformation of seabed by deposition of sediment accelerated by derelict net fishing gear.

Origin of ghost fishing issue: Because of wide-spreading use of synthetic fibres for netting materials in the 1960's and their non-degradable character, consequences after gear loss drew attention. It is said sometimes that continuous kill of animals and impacts to aquatic environment by derelict fishing gear started because of application of non-degradable materials

Fig. 1 (Left) A dead octopus in a lost fish-pot found underwater in a coastal fishing ground in southern Kyushu, Japan (approximately 14m deep). (Right) Aged gillnet deliberately tangled around an artificial reef, on which a sea bream is entangled (approximately 25m deep).

to fishing gear those days.[1] The fact is, however, as proved later in this report, ghost fishing is the most serious immediately after gear loss and declines very rapidly. Therefore, even fishing gear made of natural materials is not free from the problem. It is beyond a fact to say that ghost fishing is a new problem in contemporary fisheries since introduction of synthetic fibres.

Active researches on derelict fishing gear and ghost-fishing started in the 1970's.[1, 2, 3, 7, 8] Early researches tried to find the evidences to prove the truism of ghost fishing. Possibility of ghost fishing for types of fishing gear was reviewed as early as in the mid 1980's by High,[9] where those only in gillnet and pot fisheries were discussed. The author has carried out extensive field surveys underwater and has found almost all types of fishing gear and their fragments, however, ghost fishing were evidenced with dead bodies of animals only in pots (cage-type traps), gillnets including trammel-nets and small seine nets made of webbing similar to that of gillnets.

Pots (Cage traps): Early studies on ghost fishing by pots were conducted for mainly crustaceans by Sheldon and Dow,[2] High,[3] Smolowitz,[1, 10] and Pecci *et al.*[8] mainly in North America during the 1970's. A variety of *in situ* experiments using pots deliberately set for monitoring were carried out,[11, 12, 13, 14, 15] where mainly mortality per unit gear and the ratios of escapement were observed for entrapped crabs and lobsters. Breen[16] conducted a sector-wide research on ghost fishing in a pot fishery, where the ghost fishing mortality for Dungeness crab was estimated to be equivalent to 7% of the landing amount in the studied sector. On the other hand, one study reported numerous exits of the entered spiny lobster and slipper lobster and little direct mortality in pots in comparison to the total mortality in their population and, consequently, concluded as ghost fishing by those pots should be periferal.[13]

After finding the evidences of ghost fishing mortality, researches were oriented towards those on the process to induce ghost fishing. Matsuoka *et al.*[17] carried out underwater observation of lost pots in a coastal fishing ground in Japan. Many commercial finfishes and octopus were observed in pots remaining the original structures. Fewer organisms were observed in pots largely deformed due to breakage of frames, buried in sediment and covered by accumulated fouling organisms. These phenomena likely reflect the time elapsed since gear loss, therefore, the function of ghost fishing of pots was conjectured to decline along a time course.

The organisms confined in a pot demonstrated a variety of unusual behaviour such as bumping on net webbing inside, which they never show under the natural environment. A hypothesis is that the unusual behaviour is attributable to the high density and consequent stress in a pot for the animals which seldom meet in natural fauna.[18] The mortality induced by unusual behaviour and subsequent injury observed in pots was clearly indicated by the correlations among them. Such behaviour was largely different from species to species. The contents of the digestion organs of entrapped fishes were analysed and few empty ones were found. This proves that entrapped fishes eat and starvation is not a reason of mortality.

Fig. 2 (Left) Fish bones scattered on the foot of an artificial reef deliberately-tangled with gillnet, recorded during an experiment (approximately 25m deep). (Right) Rabbitfish injured in a lost fish-pot due to unusual behaviour, or bumping on net webbing from inside, of which snout has disappeared and the brain is naked and which died in the next day.

Long-term observation indicated that some pots in shallow waters can maintain the ghost-fishing functions for longer than 3 years. As described, 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 both in shallow waters. The capture function of a derelict pot is, therefore, conjectured to last for a relatively short period of time in shallower waters. Deep-water pots which are less damaged by waves and less fouled biologically may continue ghost fishing for longer than those in shallow waters.

Gillnets: Remaining of derelict gillnets in fishing grounds was first evidenced in the mid 1980's. [19, 20] Several high-quality studies which observed ghost fishing of finfishes and crustaceans by bottom gillnets and trammel-nets under both natural and experimental conditions were conducted after the mid 1990's in United Kingdom, [21] Portugal, [22, 23] Norway, [24] Spain, [25] Sweden, [26] and Japan [27, 28] mortality per gear became quantitatively assessed.

The number of enmeshing a gear a day and its ratio to the original CPUE were major research targets. The duration for which ghost fishing continues is different from species to species. [27, 29] The main ghost-fished species are replaced along the time course since gear loss, [27] as sub-demersal swimmers, *e.g.* sea bream are caught in the first several days and seabed dwellers, *e.g.* dragonet, for a longer period of time.

In principle, ghost fishing mortality by a gillnet declines since dislocation of gear [21, 22, 23, 25, 26, 27] and continues for a relatively short period of time, *e.g.* for a few weeks to several months, [30] though a marginal amount of mortality continues for much longer period of time. Consequences for derelict gillnets are strongly affected by the seabed environment. [28] The ghost-fishing function of gillnets on the flat seabed declines rapidly with decreasing heights [21, 22] and increasing visibility due to fouling. Decline in net height is mainly attributable to debris on meshes, subsequent increase of weight and hydrodynamic resistance and to gradual sticking on small projections on the seabed. A gillnet vertically expanded around an underwater structure maintains the initial magnitude of ghost fishing for a much greater extent of time even after badly fouled. Revil and Dunlin [31] reported that gillnets tangled over a wreck maintained the stretched area of webbing and ghost fishing continued for longer than 2 years. A gillnet which was experimentally tangled around an artificial reef was left for longer than 3 years and so badly fouled as the netting monofilament was no longer visible maintained the ghost fishing function at the same level as the original. [28] Since gillnets are easily tangled on three-dimensional structures such as artificial reefs, wreck ships and large rocks, the above fact may provoke such a serious problem as the ghost fishing mortality of fishes aggregated by those structures.

Ghost fishing of crabs and lobsters by so badly damaged gillnets or even their fragments of which the original structure no longer remains is frequently observed. This suggests that ghost fishing by lost gillnets continues perhaps longer in non-finfish animals such as crustaceans. [21, 22]

Other types of fishing gear: Small boat seine and beach seine nets are made of Polyamide net webbing made of thin lines which are usually used for gillnets in particular in developing countries where the available variation of net webbing is limited. The author observed ghost fishing mortality by such a small boat seine net in coastal water in Japan. It is reasonable assumption that derelict longline gear without bait cannot continue the capture function, therefore, the need to consider its ghost fishing is marginal. Divers can observe a large number of derelict bottom longlines and their fragments tangled around rocks and reefs, while the author have observed no capture of fish by a derelict bottom longline. We can conclude the possibility of ghost fishing by derelict line fishing gear is minimal.

Information availability: As overviewed above, ghost fishing has been studied mainly in the countries in North America and Europe and a small number of other countries as; Kuwait, [32] Japan, [29] Australia, [33] and Oman, [34] though beach-survey type information on fishery-origin marine debris is available in some other countries, too. Information availability is largely biased among countries and regions. The author found few derelict fishing gear with an exception of line fishing gear in an extensive underwater survey around the coastal waters in Panay and Guimarus Islands in the Philippines. Interviewed fishermen stated that they never set their net

fishing gear in such a fishing ground where the possibility of gear loss is high and retrieval of lost gear is difficult. This is because that net fishing gear is an expensive asset for local fishermen. It is a hypothesis that fishermen take a risk of gear loss in fishing operation in such countries where fish price is relatively high in comparison to gear price. It is important to recognise that the information available today particularly about fishing gear loss should not be generalised over the world.

5. Issues other than ghost fishing

Fish attraction/aggregation: It is a common question if derelict fishing gear has a function of fish aggregation as FAD and if such a function has a positive effect to resources and environment. A large number of fish is usually observed around lost and aged pots. [17] It is empirically true that derelict fishing gear likely has the micro-FAD effects to attract and aggregate fishes. Gillnets entangled on artificial reefs apparently increase their fish aggregation efficiency. [28] These are, however, not inevitably positive. Among the fishes aggregated around the artificial reef, the numbers of individuals of the species of which ghost fishing mortality was observed did not increase. [28] This may suggest mortality of ghost-fished species and support a hypothesis that the aggregated fishes are killed and accelerate ghost fishing.

Sank aquaculture cages and large fishing gear such as trawl nets made of thick twine materials form a large number of small compartments inside and likely support spawning and protect juveniles. This may increase recruit to the resource, though it has not been studied yet. The fish community newly formed around derelict fishing gear is different from the natural ones in the vicinity. There may be a new prey-predator relationship and its consequence is still unknown.

Incidental catch of non-fishery animals other than ghost fishing: In the 1980's, it became evident that even fragments of derelict fishing gear which no more remain the original capture function cause mortality of a variety of wild life. [35, 36] Researches on this issue were conducted earlier than those on the ghost fishing of finfishes and crustaceans and a variety of reports and discussions appeared in 1984; *i.e.* papers on incidental catch of marine mammals including whales, [37] pinnipeds, [38] fur seals, [39, 40] monk seal, [41] and sea lions, [42] as well as marine reptiles. [T37, T43] These research outcomes were perhaps attributable to partly that the phenomenon is observable in ambient. Researches on incidental catch or entanglement of non-fishery animals such as marine mammals [33, 44, 45, 46, 47, 48, 49, 50, 51] and marine reptiles [52] and seabirds, [53, 54] on net and line fishing gear were continued beyond the late 1980's.

Marine mammals with a fragment of net piece which are known as neck collars [33] were documented in Hawaii and Australia. Only a few researches assessed, however, the number of entanglement quantitatively. [51] It was reported that approximately 1.5-2% of Australian fur seals in Bass Strait and off southern Tasmania were found with entangled fragments of trawl nets.

It was documented that sea turtles are peculiarly prone to tangle themselves in derelict lines and netting and are killed.[52] Mortality of seabirds by derelict salmon driftnets was surveyed in the North-west Atlantic Ocean. [35] Entanglement of seabirds by lost monofilament lines has been photographed and publicised. However, such impacts by commercial bottom longlines have not been scientifically reported yet. This possibility may be peripheral because the commercial bottom longline gear is composed of relatively thick monofilaments and lost longlines are usually extendedly hung around reefs and rocks underwater.

In the history of the studies of derelict fishing gear issue, the mortality of the non-fishery animals as above are referred to as entanglement in/on marine debris. They have not been usually dealt in the category of ghost fishing traditionally. The early start of the researches on this issue and active publications during the 1980's and 1990's are conjectured to reflect the international disputes about the trawl fishery in the Bering high-seas and the high-seas large scale drift-net fisheries in the Pacific Ocean those days.

Other phenomena provoked by derelict fishing gear: Problems of accumulation of fishing gear on seabed including entanglement on coral reefs, and contamination on beaches mainly by net fishing gear [34, 45, 49, 50, 55, 56] together with the cases of other fishing gear and its parts [57, 58] have been discussed. It is concerned if accumulation of non-degradable materials may cause

declining sea bottom environment. [33, 57, 58, 59, 60, 61] Several studies on *in situ* distribution of derelict fishing gear on seabed have been conducted by using trawl net, retrieval devices and scuba diving, [34, 45, 49, 61, 62, 63] however, there are few quantitative assessment on the impacts to the seabed environment. There is a research which concluded little apparent damages are given to reef habitat by wire-made pots. [62]

The author has observed deformation of the seabed as spaces around rocks are buried with sediment and changed to flat bottoms when rock reefs are covered by lost nets. A hypothesis is that the regional flow around a net is decelerated due to fouling organisms accumulated on meshes, and consequently, deposition occurs. This may simplify the seabed environment and reduce biodiversity and productivity, 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 or not.

In addition to these biological and ecological impacts, navigation hazard is also discussed in a series of International Marine Debris Conferences (Carroll S., per. comm., 2000).

6. Quantitative assessment related to ghost fishing

Assessment of mortality per gear: The death ratios to the number of entrapped animals in a pot are the most popularly available data. The variation of the reported values are very large; *i.e.* 7.1% for king crab in a pot for the particular species, [64] 19% for Dungeness crab in a crab pot, [14] 22% for Hawaiian lobsters in a lobster pot, [13] 25% for American lobster in a pot for the species, [8] 39% for Tanner crab in a ground-fish pot, [65] 44% for octopus and less than 14% for finfishes in a fish pot, [18] 45% for blue crab in a pot for the species,[15] 55% for Dungeness crab and 94.6% for snow crab in a crab pot, [8] 95% for snow crab in a pot for the species, [66] 100% for both brown crab and lobster in a Tanner crab pot. [67]

Some researches directly obtained mortality a gear a unit period of time experimentally. [8, 12, 15] The mortality rate changes along the time after gear loss. [7, 18] Breen [11] assessed the mortality of Dungeness crab in a pot to be 9.3 individuals per pot per year. Bullimore *et al.* [12] assessed the mortality of brown crab to be a minimum of 6.1 individuals and lobster, a minimum of 0.44 per pot per year. Pecci *et al.*[8] reported that the ghost fishing mortality of lobster for an inshore-type lobster pot was 13% of the original CPUE of the studied gear.

There is no report of the death ratio to enmeshed ones for gillnets. This is attributable to the assumption of the entire kill of the enmeshed population. Revil and Dunlin and the authors found declining of the ghost fishing function of bottom gillnets depends on seabed conditions where the nets are lost. [28, 31] It was also reported that the mortality or catch changed complicatedly together with seasons, elapsed time, and associated species.[12, 67, 68]

Duration remaining capture function: There are several researches on the duration for lost fishing gear to remain the capture function. Continuous catch of crustaceans by pots for longer than one or more years even though the efficiency declined.[12, 67] Matsuoka *et al.* found finfish pots even in a shallow-water continued ghost fishing as long as for three years sometime.[17]

The duration of ghost fishing by gillnets depends on the seabed structure where they are tangled, while there are reports as continuation for longer than nine months [21] and disappearance after 15 to 20 weeks. [22] Nakashima and Matsuoka [27] found the catch efficiency declined to 5% of that of the original gear approximately in 20 weeks in the case of flat seabed while those tangled around an artificial reef maintained almost the original catch rate even after three years. Only Humborstad *et al.* [24] which reported the ghost fishing function declined after gear loss, however, levelled off at approximately 20% of the original magnitude of mortality.

The number of ghost fishing gear in a fishing ground: The number of ghost fishing gear was not dealt in the early ghost fishing studies. [19, 69] The number of lost fishing gear in a unit area of a fishing ground became to be studied in the late 1990's, as surveys of a crab-pot fishery by using side-scan sonar in Alaska [67, 70] and a finfish-trap fishery by diving in Japan.[17, 18] There are a very small number of researches which dealt the ratio of the functional lost gear and the area of ghost fishing ground, with an exception of those by Matsuoka.[18] Recently, researches to

estimate the number of fishing gear loss in a fishing sector from interview or questionnaire to fishermen are becoming popular instead of estimation of the number of lost fishing gear underwater. [11, 23, 25)]

Quantitative information on mortality in a sector: The experimental studies on the ghost fishing functions of individual fishing gear have not been developed yet to large-scale assessment of ghost fishing in a fishing sector. Case studies on quantitative assessment of ghost-fishing mortality in a sector or over a fishing ground are available in Canada, [11)] Japan, [18)] Spain [25)] and Portugal. [23)] Breen [11)] estimated that the mortality of Dungeness crab in a pot fishery in Fraser River Estury in Canada is equivalent to 7% of the landing amount in the pot fishery in the studied district. Matsuoka [18)] estimated that the mortality of octopus in a pot fishery in a coastal fishing ground in a district in Kagoshima, Japan is equivalent to or two times more than the total commercial landing amount of octopus in the studied district. Sancho *et al.* [T25)] estimated that the mortality of monkfish in a gillnet fishery in Cantabrian Sea in northern Spain is equivalent to 7% of the landing amount in the fishery. Santos *et al.* [23)] estimated that the mortality of hake in a gillnet fishery in Algarve, southern Portugal is equivalent to 0.5% of the landing amount in the fishery in the studied region.

7. Methodological development to estimate ghost fishing mortality

New approaches to estimate ghost-fishing mortality per gear were started by Kaiser *et al*., [21)] Erzini *et al*., [22)] and Nakashima and Matsuoka [27)] recently. They obtained an experimental equation to represent the chronological decline in ghost fishing mortality and integrated it over the duration for which ghost fishing mortality function remains in order to estimate the number of mortality per gear for a lost gillnet.

Model for mortality estimation: Matsuoka summarised the above researches and developed a simplified model for quantitative evaluation of ghost fishing on the basis of the above researches. [18, 71)] Ghost-fishing mortality, N_m of a species or a group of animals in a fishing sector in a fishing ground over a unit period of time, such as a year, is denoted as;

$$N_m = E_d \cdot m \qquad \ldots\ldots (1)$$

where E_d is the number of fishing gear loss in a fishing sector in a unit time period such as a year and m, the ghost-fishing mortality per gear for a species or a group of animals during a period of time until the ghost-fishing function ceases. E_d and m must be estimated individually as below. This model is equivalent to that widely used in fisheries science to assess fishing mortality from devoted fishing effort and CPUE [71)] and has an advantage where data appearing in usual fishery statistics are usable.

Micro-assessment: The author proposed a concept of Ghost Fishing per Unit Effort (GPUE), m and the estimation of m for an individual fishing gear is referred to as micro-assessment. The ghost-fishing mortality rate, $N_m(t)$ of a unit fishing gear in a given fishing sector can be assessed mathematically on the basis of a probability model with monitoring dead bodies of animals in/on fishing gear underwater. [28)]

In order to represent the declining trend with the elapsed time (*e.g.* days), t since gear loss, a variety of equations have been proposed. The most general fashion of the equation is a simple survival function as;

$$N_m(t) = a \cdot (1 - b)^{t} \quad \ldots.. (2)$$

where the a and b are constants to be determined by *in situ* data. The integral of the equation from t=0 to T_{max} gives the accumulated ghost fishing mortality, m. T_{max} is the day when the ghost-fishing ceases.

$$m = \int_{t=0}^{T_{max}} N_m(t)\, dt \qquad \ldots.. (3)$$

Macro-assessment: The number, E_d of derelict fishing gear a year in a sector is estimated as;

$$E_d = N_f \cdot r_o \cdot N_g \cdot r_l \qquad \ldots\ldots (4)$$

where N_f is the number of fishing unit, *e.g.* fishermen or fishing vessel, r_o is the ratio of units actually operating among N_f, N_g is the average number of fishing gear used by individual fishing unit, and r_l is the average ratio of the annual gear loss among N_g. It is a practical approach because these parameters are obtainable through interview or questionnaire to fishermen in ambient.

Application of the estimation method: Kaiser *et al.*, [21] Erzini *et al.*, [22] Nakashima and Matsuoka, [27] Sancho *et al.* [25] and Santos *et al.* [23] formulated the descending trend in mortality since loss of bottom gillnets. Integrations of the reported formulae up to the day when the gear efficiency declines to 5% [27] of the original one gave the duration of ghost fishing for 30~328 days and mortality of 84~455 animals per net 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 (these values are different from those in the original papers due to recalculation by the authors of this report [28]). 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.

There are a very few researches on the equation of declining trend of ghost fishing by pots. In a case study by the author, experiments on the basis of this methodology estimated the mortality of 283 individuals including 70 octopuses for 522 to 602 days induced by a coastal fish pot with two side-entrances.

8. Development of countermeasures

Countermeasures have been discussed and tested right after the early recognition of the ghost fishing issue. The countermeasures against ghost fishing are prioritised in two aspects as; (1) countermeasures before fishing gear loss such as prevention of fishing gear loss, and (2) those taking given gear loss into account such as retrieval or dysfunction of lost gear and development of designed disabling of lost fishing gear.

Prevention of fishing gear loss: Prevention of fishing gear loss is the most essential solution against ghost fishing. The reasons of fishing gear losses are mainly; (1) entanglement of gear or its accessory parts around seabed to unable hauling, (2) cut of float line and dislocation due to interaction with other fishing activities, (3) misplacement during operations, and (4) drop of fishing gear either accidentally or intentionally. Taking these into account, management of fishing operations in order to avoid confliction among different fishing sectors and legal prohibition of discarding fishing gear at sea are practically applied. [72, 73]

Entangling of fishing gear around bottom rocks and reefs are avoidable in a certain extent by technical improvement of fishing gear and methods, *e.g.* an intermediate float on buoy line for bottom-set fishing gear can prevent the line from entanglement on the seabed. The true reason of gear loss is, however, that some fishermen choose precarious fishing grounds, taking potential gear loss into account as a risk, in particular, where fishing gear is relatively inexpensive. Increasing public awareness of the long-term impacts to the resources by ghost fishing is the solution.

Small fishing gear is destructed by larger gear, where multiple types of fishing gear are used in the same fishing ground. The breakage of float lines by larger drag-net operations and mooring ropes of aquaculture cages are typical examples.[17] These problems may be intensified where a variety of human activities are mixed up and multiple utilisation of coastal fishing grounds are encouraged. Rationalised management of multi-sector fishing in coastal fishing grounds must be taken into consideration in coastal zone development and management strategies.

Possibilities of phenomena in the categories (3) and (4) above may be marginal for fishermen equipped with high-technology position-fixing devices such as DGPS, however, set fishing gear is misplaced due to storms and strong currents from time to time. [74] Nets and pots are set with

submerged markers in order to avoid theft and naturally misplaced by fishermen themselves in some countries. Education and promotion of moral and social welfare are important particularly in deprived communities to support 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 [72, 73] and developing disposal services to collect used fishing gear.[29]

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, [74, 75] however, it is suspected if further damages to the seabed may be provoked by retrieval devices. The author recommends a technique to tow a heavy chain of which rings are partially cut and sharpened. It is easy to handle even around a rough bottom and less damages to the bottom environment because of no nail despite the highly efficiency in retrieval. Voluntary cleaning of seabed and dysfunctioning of derelict fishing gear are educationally effective, however, they are hardly practical and essential solutions due to high cost to efficiency and limited use in shallow waters.

Designed degradation of ghost fishing gear: Techniques for rapid degradation of lost fishing gear parts have been tested since the early stage of the ghost fishing researches, as Smolowitz [1] reviewed. Blott [76] carried out extensive and detailed practical tests as early as in the mid 1970's to determine the optimum materials for the time-releasable escape gap to a pot which opens after immersion for a certain period of time. There are many experimental data to prove effectiveness of partial use of degradable twines and plates for fishing gear for reduction of confinement of animals. Crabs entrapped in pots made of degradable materials together with a gap escaped at 99% in comparison to 0% from conventional ones and that of sub-legal size crabs, at 80~99%. [70, 77] This technique is well developed now as the time required to dysfunction since lost is controllable. It is already of practical application in fishing regulations in some countries, [65, 67, 78, 79, 80] Usage of such electro- and bio-degradable materials to net webbing and rigging of parts, *e.g.* floats of gillnets, are also tested. [70, 81]

These techniques are successful for pots. [8, 12, 14, 65, 76, 77, 79, 80] This is attributable to that the ghost fishing function of pots declines slowly and a technically allowable time is long enough for control of the time period needed for degradation of parts. Usage of degradable materials must be carefully evaluated, taking the fact into account that ghost fishing is most serious immediately after gear loss for example only within a couple of days for some species in gillnet. [27] In such cases, it is not realistic to satisfy both intended degradation and required durability for fishing gear materials under a variety of environmental conditions.

Mobility of derelict fishing gear: One of the most serious concerns against solutions today is derelict fishing gear drifts and moves to vulnerable places other than the original fishing ground. Derelict fishing gear entangled on, in particular, coral reefs are hardly recoverable due to possible destruction of corals. [55] These may cause irreversible destruction of marine environment and magnify the problems of derelict fishing gear. [45, 49] Derelict gear drifted and piled up in Hawaii and the other Pacific islands are, for example, mainly trawl nets [49] which are not locally used and assumed to be of a foreign origin. Identification of their origin is a global concern, because when derelict gear is swept away from the original fishing grounds as the above, the people of the damaged areas are not responsible to the problem and it may provoke external conflicts either internationally or domestically.

Lost fishing gear does not necessarily stay in the original fishing ground. According to the author's survey, derelict fishing gear drifts and approaches toward shallow waters and beaches. A variety of bottom conditions (including beaches) have different power of holding the arrived fishing gear. Derelict fishing gear repeats being stuck and released around shallow waters and end up to the places where the holding power is the strongest. This is the mechanisms that lost fishing gear is distributed around thorny bottom environment and on the beaches.

8. Prevention of derelict fishing gear and ghost fishing

The most important but less studied area in this field 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 is an alternative way. Prevention of fishing gear loss is the most fundamental countermeasure. Researches towards the following countermeasures are essential as;

(1) Management of duplicated utilisation of fishing grounds by multiple fishing sub-sectors 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 been assessed yet, it is convincing that the issue is no more at a peripheral level. The challenge to assess and to reduce the problem must secure the future of the fishery industry because the resources currently wasted by ghost fishing could be converted to new resources additional to human consumption.

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Ghost-fishing impact by derelict fishing gear

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- **Global concern to negative impacts in capture fisheries**
  - **Bycatch and discards**
  - **Derelict fishing gear and ghost fishing**
  - **Destruction of habitat**
  - **Less selective fishing activities**

Impacts by derelict fishing gear

- Ghost fishing (Sheldon WW. 1975; High WL. 1976 *etc.*)
- Incidental mortality of non-fishery animals as;
  - Marine mammals
  - Marine reptiles
  - Sea birds
- Accumulation on seabed and coral reefs
- Contamination on beaches
- Deformation of seabed by deposition
- Increasing fish aggregation efficiency of FAD
- Micro-FAD effects to aggregate fishes
- Navigation hazard

What is ghost fishing?

Derelict fishing gear no matter if abandoned intentionally or not and removed from fisherman's control remain its capture function in aquatic environment and continue inducing mortality to fishery organisms.

(Octopus in cage pot)

(Sea bream on gillnet)

Evidences of ghost fishing (1980's)

Quantitative assessment of mortality (since late 1990's)

(Lobster on a gillnet)

(Flatfish in a pot)

Proposed model for estimation of GF mortality

$N_m = E_d \cdot m$ ..... (1)

N_m : Number of GF mortality
E_d : Number of fishing gear lost/abandoned in a unit time period
m : Number of GF mortality per gear

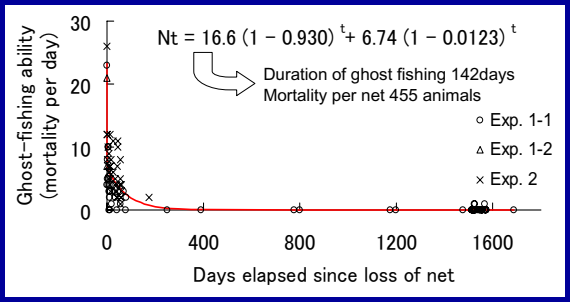
(1) Micro-estimation (estimation of m)
- Equation to represent change in GF mortality along time
- Integral to find total GF mortality toward T_{max} (cease of GF)

(2) Macro-estimation (Number of derelict gear E_d then N_m)
- Field survey to find the total number of fishing gear loss

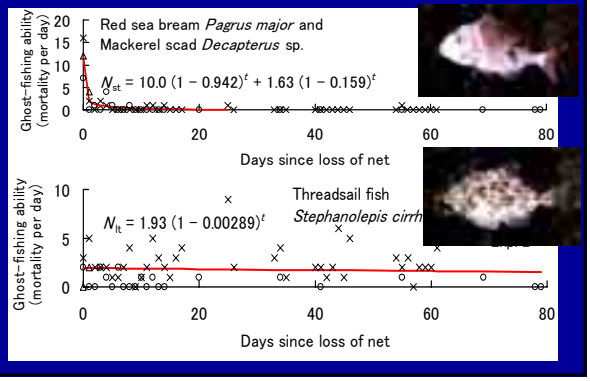
Ghost fishing by gillnets left on flat seabed

- Experimental methods: Finding the number of enmeshed fish a day
  (1) Setting a 72m-long gillnet on flat seabed,
  (2) Observations on consecutive two days,
  (3) Monitoring for 1,689 days.

Representation of observed GF-mortality by a gillnet with experimental equation



Different durations of GF-efficiency for fishes

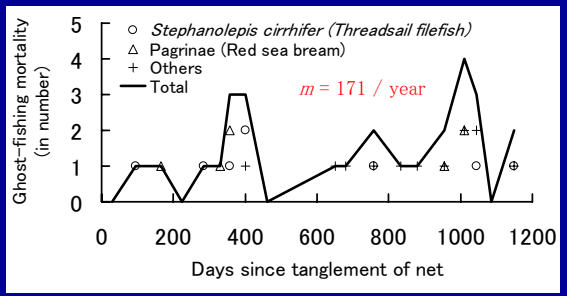


Accumulation of data by researches on GF by gillnets on flat seabed

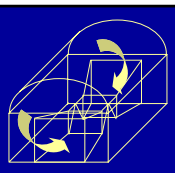
	Kaiser *et al*.	Erzini *et al*.	Nakashima & Matsuoka
Net length (m)	90	100	72
Net height (m)	3.0	2.1	2.3
Mesh size (mm)	100	60	60 to 99
Maijor GF species	Cat-shark	Scorpionfish	Threadsail filefish
	Nursehound	Seabream	Dragonet
GF duration (days)	141	56	142
GF mortality (mumber)	334	318	455

Ghost fishing by gillnets 3-dimmensionally tangled on FAD

Observed Ghost-fishing mortality by a gillnet tangled on FAD



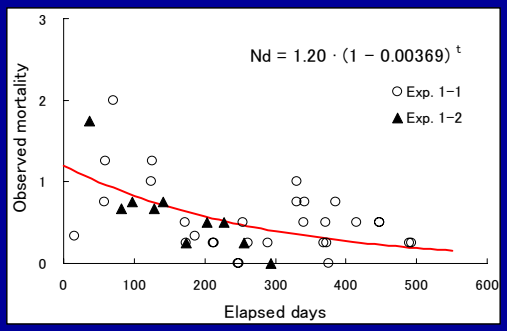
Ghost fishing by pots



Setting 4 pots in 10-24 m depth
Underwater observation for 492 days;
(a) Number of observed live organisms
(b) Number of observed dead bodies
(c) Number of injury

Ghost-fishing process in pots: unusual behaviour, injury and subsequent mortality

Observed numbers of dead bodies of entered organisms in a pot



Estimated numbers of entry and mortality in a pot

		All species	Finfishes	Octopus
Live organisms	Declining rate	0.00203	0.00222	
	$T_{0.05}$	1,480	1,350	2,110
	Integral to $T_{0.05}$	6,759	5,472	1,287
	Observable days	2.80	3.18	1.64
	Number of entry	2,414	1,721	785
Deadbodies	Declining rate	0.00369	0.00434	
	$T_{0.05}$	810	690	1,030
	Integral to $T_{0.05}$	313	189	148
	Observable days	0.99	0.81	1.52
	Number of mortality	315	233	98

Macro-estimation of ghost fishing mortality

Estimation of *Ed* (number of derelict fishing gear during a unit period of time) based on interview surveys

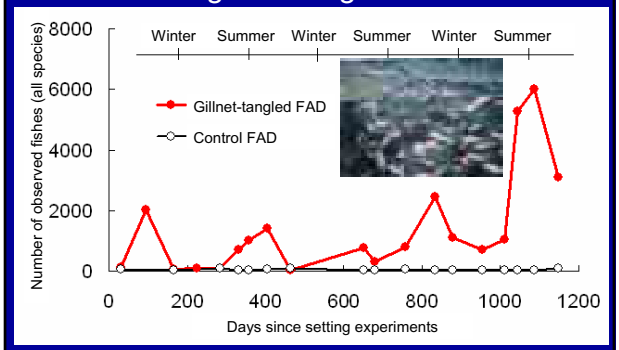
$$E_d = N_f \cdot r_o \cdot N_g \cdot r_l$$

N_f ; Number of registered fishermen
r_o ; Ratio of presently operational fishermen
N_g ; Number of fishing gear used per fisherman
r_l ; Ratio of annual gear loss

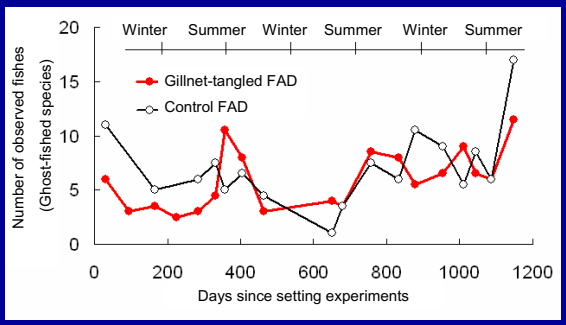
GF by other types of fishing gear: small Danish seine and bones of entangled fish

Micro-FAD effects by derelict fishing gear and aquaculture cages (large fishing gear)

Increasing fish-aggregation efficiency of gillnet-tangled FAD



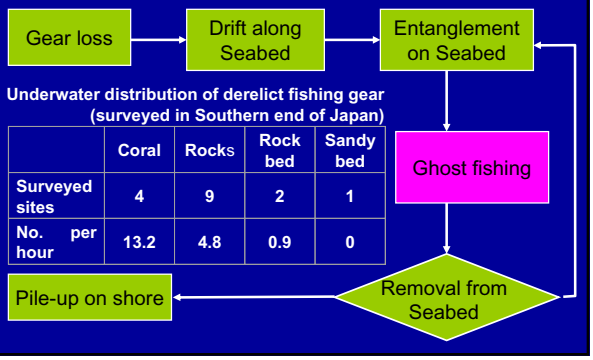
Un-increasing fish-aggregation in gillnet-tangled FAD for ghost-fished species



Distribution of fishing gear and parts underwater and on-shore

	Coral	Rocks	Rock bed	On shore
Webbing	0.32	0.30	0.00	0.19
Line	0.68	0.68	1.00	0.02
Sinker line	0.00	0.02	0.00	0.01
Float	0.00	0.00	0.00	0.64
Float line	0.00	0.00	0.00	0.02
Plastic trap	0.00	0.00	0.00	0.12

Process from gear loss to dysfunction of ghost fishing



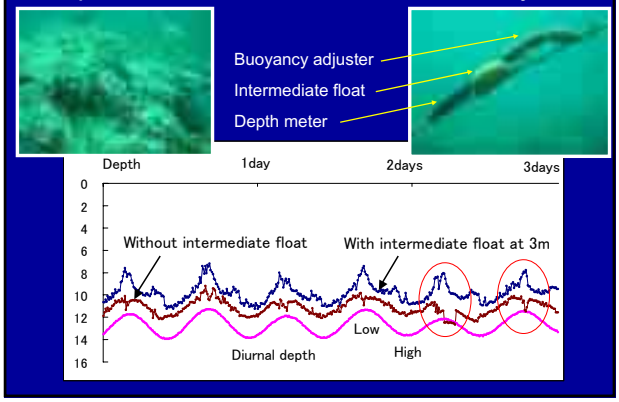
Underwater distribution of derelict fishing gear (surveyed in Southern end of Japan)

	Coral	Rocks	Rock bed	Sandy bed
Surveyed sites	4	9	2	1
No. per hour	13.2	4.8	0.9	0

Countermeasures against ghost fishing

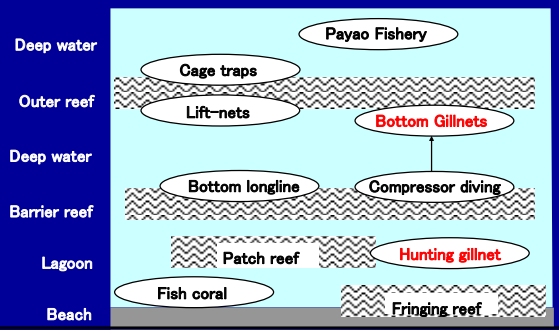
- Reduction of fishing gear loss by preventing;
  (1) cut of float line due to interaction with other sectors,
  (2) entanglement of gear around seabed to unable hauling,
  (3) misallocation during operations,
  (4) improper setting of fishing gear *e.g.* to avoid theft,
  (5) drop of fishing gear either accidentally or intentionally,
  (6) cut of float lines by boats.
- Retrieval or dysfunction of derelict fishing gear.
- Designed degradation of derelict fishing gear.
- Responsible behaviour and systematic cycle of purchase-use-replacement-treatment of fishing gear (and materials)

Experiment of intermediate float on buoy line



Retrieval of derelict fishing gear by iron clasp device

Avoidance of fishing gear loss in traditional coastal fishery in the Philippines



Prevention of derelict fishing gear and ghost fishing

The most important but least studied areas are the technical and legislative countermeasures. Fishing gear loss is an economic loss to business viability for fishermen and the worst 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. Researches towards the following countermeasures are essential as;

(1) Management of duplicated utilisation of fishing grounds by multiple fishing sub-sectors including aquaculture; and

(2) Improvement of fishing gear and methods before loss, when they are used in fishing grounds where gear loss may occur.