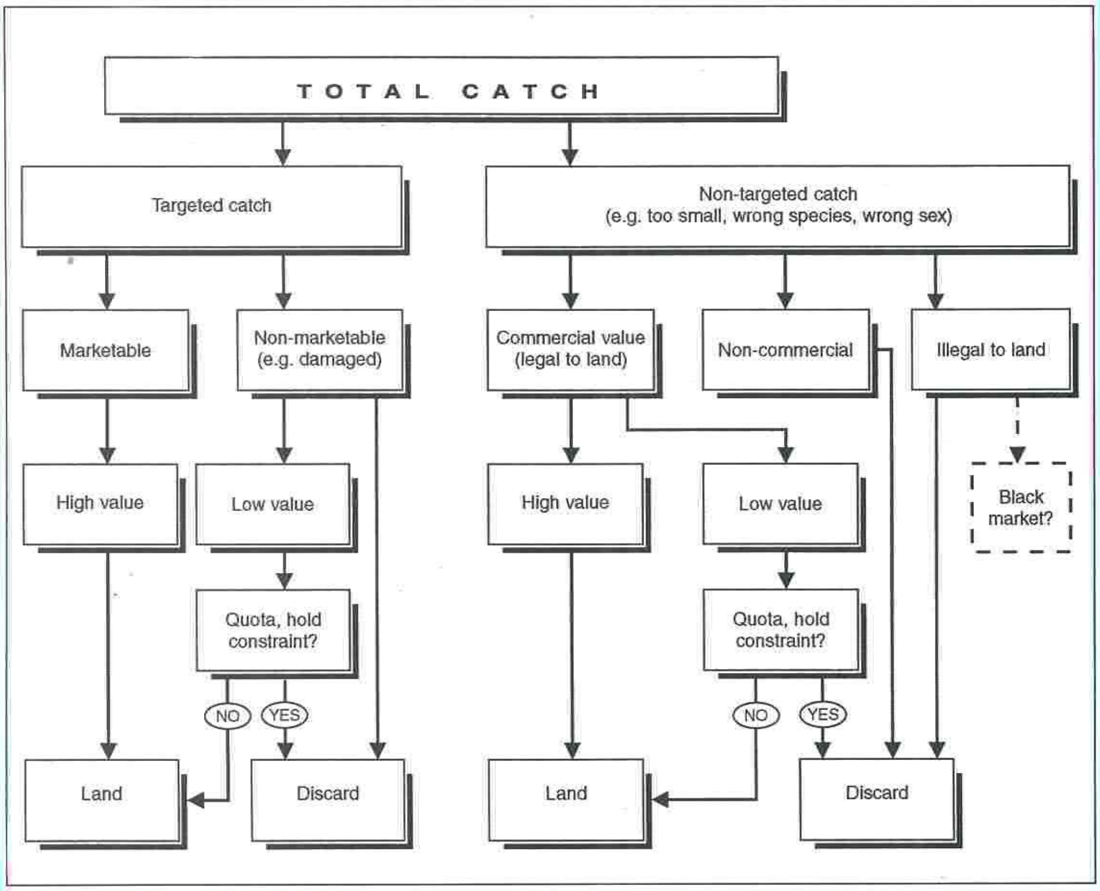
ISSN 0429-9345

Bycatch management and the economics of discarding

FAO FISHERIES TECHNICAL PAPER

370



Food and Agriculture Organization of the United Nations

Bycatch management and the economics of discarding

FAO FISHERIES TECHNICAL PAPER

370

AF

by
S. Pascoe
University of Portsmouth
United Kingdom

Food and Agriculture Organization of the United Nations

Rome, 1997

M-43
ISBN 92-5-104043-5

PREPARATION OF THIS DOCUMENT

This document has been prepared for fisheries scientists and administrators who are concerned about the sustainability of capture fisheries and the improvement of conservation and management of stocks. A number of initiatives have been taken recently to address the issue of bycatch and discards in general and this document brings the focus to bear on the economic aspects in particular.

Mr Sean Pascoe works for the Centre for the Economics and Management of Aquatic Resources (CEMARE), University of Portsmouth, Locksway Road, Southsea, Hants, PO4 8JF, United Kingdom.

The bibliographic references are presented as given by the author.

Distribution:

FAO Fisheries Department
FAO Regional Fishery Officers
Author
Selected institutes and projects
Directors of Fisheries

Pascoe, S.
Bycatch management and the economics of discarding.
FAO Fisheries Technical Paper. No. 370. Rome, FAO. 1997. 137p.

ABSTRACT

The increase in commercial fisheries production over the last 50 years has been accompanied by an increase in the level of incidental catch and discarding of a number of species. Approximately one quarter of the marine commercial catch destined for human consumption is discarded at sea. This has raised concerns by a number of groups in society, including environmentalists, humanitarians and fishers themselves.

In this paper, the economic incentives to discard fish are examined. The effects of different management policies on these incentives are also investigated. The concept of an optimal level of discarding is discussed taking into account the externalities that can be created by discarding. Finally, the effectiveness of various measures to reduce the level of discarding is reviewed. These including technical, administrative and economic measures.

ACKNOWLEDGEMENTS

I would like to thank a number of people for their useful comments on earlier versions of this document. In particular I would like to thank Louisa Coglan from the Department of Economics, University of Portsmouth and Catherine Robinson from CEMARE, University of Portsmouth for reading through the earliest versions of the document and providing useful comments. I would also like to thank Rolf Willmann from the FAO for providing extensive and useful comments on the document. Ulf Wijkström and George Everett from the FAO also provided useful comments and feedback. Ivor Clucas from the FAO provided a number of documents that proved extremely useful in the completion of the report.

CONTENTS

List of Tables

List of Figures

Executive summary

The practice of discarding is a common feature of many fisheries around the world. Records of discarding unwanted catch date back to biblical times. As a wide variety of fish species occupy the same habitat, fishers are generally unable to catch individual species without some unintended catch of other species. This incidental catch is known as bycatch. Where the bycatch has little or no commercial value, the cost involved in landing the fish (such as storage, icing and freight costs) may exceed the price received. In such cases, the fisher is better off disposing of the fish rather than landing it. Not all bycatch is discarded as some bycatch has a commercial value to the fisher.

In total, between 18 and 40 million tonnes of fish are thought to be discarded annually, representing roughly 20 per cent of the total marine harvest. This has led to concerns by environmental groups of the possible effect the unintended harvest is having on the fish populations. This is particularly the case as a number of species caught as bycatch are endangered (e.g. certain species of turtles) or attract significant public concern (e.g. several species of marine mammals and seabirds). In contrast, humanitarian groups are concerned about the apparent waste of a potentially valuable food source in a world where millions of people remain undernourished.

Discarding also produces a number of economic impacts. Discarding commercial target species results in a direct cost to the fishing industry in the form of foregone income. Where fisheries interact, discarding in one fishery can reduce the potential revenue in another. Also, the cost associated with trying to collect information on the level of discarding for the purposes of stock assessment may be considerable in some fisheries.

While some level of discarding occurs in nearly all fisheries, some fisheries management policies aimed at conserving the resource and improving fishers' incomes have led to an increase in the level of discarding. Minimum landing sizes, aimed are reducing the capture of juvenile fish, have led to the discarding of undersized fish. Similarly, output controls such as individual transferable quotas and trip limits have created economic incentives for 'highgrading' the catch by discarding smaller, less valuable fish. Where a quota or trip limit for a species has been filled, any subsequent bycatch of the species may also be discarded.

Discarding low valued fish may be considered optimal from the viewpoint of society if the cost of the resources that would be used to land the fish exceeds the value of the fish. However, the actual level of discarding observed in most fisheries throughout the world would rarely be optimal from a societal perspective. In some cases, this difference is due to distortions created by management policies. In other cases, it is a result of not all costs arising from discarding being borne by the individual fishers. Additional costs may be borne by other groups in society including other fishers in the same or overlapping fisheries, fish consumers and others in society who may experience some disutility as a result of discarding some species. Not all of these costs can be readily observed or estimated. If these costs were incurred by fishers then it is likely that they would alter their own harvesting strategies accordingly. As they are not incurred by fishers, the harvesting strategy and resultant level of discards differ from the social optimal.

In some cases, the socially optimal level of discarding may be greater than that which occurs in a poorly managed fishery. This effect results from an increase in the stock size of the bycatch species in a well managed fishery. While the level of discarding in such cases may be greater in absolute terms, the proportion of the stock lost through discarding would still be less than in a poorly managed fishery.

Where the level of discarding differs from the socially optimal level, some additional management measures may need to be introduced. Such management measures fall into three broad categories - technical measures, administrative measures and economic measures. Considerable attention has focused on the first category of these measures, which aim to reduce discarding by reducing the level of incidental catch. A range of bycatch reduction devices and gear modifications have been developed that are effective in reducing the quantity of bycatch. However, in some cases these devices also reduce the revenue of the fishers. Area and seasonal closures have also been implemented in some fisheries to reduce the level of unwanted catch or to provide a refuge for species that are being adversely affected by incidental harvesting. In some fisheries, particularly shrimp fisheries, seasonal closures have proved beneficial in both reducing the catch of juvenile animals and increasing the value of the catch. In other fisheries, seasonal and area closures have increased the costs to the fishers. Consequently, the economic effectiveness of using technical measure to reduce bycatch need to be considered on a fishery by fishery basis.

Most of the non-technical measures have been developed to counter the problems created by individual transferable quotas. Administrative measures include restrictions on the combinations of quota or the use of size-specific quotas. These aim to ensure that fishers have quota in sufficient proportion to avoid over-quota catch of bycatch species and also to encourage the landing of smaller size classes. Other administrative measures have been introduced to reduce the transactions costs facing fishers when obtaining quota.

Economic measures include taxes and subsidies, the use of deemed values, quota substitution and value-based ITQ systems. In theory, such policies can result in reduced levels of discarding. In practice, deriving the appropriate incentive is difficult as costs of fishing differ from fisher to fisher. Nevertheless, apart from the value-based quotas which have yet to be tested, such policies have been employed with some success in world fisheries.

While a variety of bycatch management options exist, no single management option can reduce discarding in every situation. Hence, a combination of policies is required.

From an economic perspective, the most desirable approach to reducing the problems associated with discarding is to reduce the total amount of effort in world fisheries.

In most fisheries, the total elimination of discards will be neither feasible nor desirable. Reducing discards below the socially optimal level may result in society not achieving the greatest benefits possible from the use of fisheries resources.

1. Introduction

The problem of bycatch and discarding in commercial fisheries has attracted considerable attention over the last decade as part of the debate on the appropriate utilisation of the world's fisheries resources. A recent study of bycatch and discarding estimated that between 17.9 to 39.5 million tonnes, with the best estimate being around 27 million tonnes, of fish are discarded annually from commercial fisheries (Alverson *et al* 1994). This best estimate has subsequently been revised to around 20 million tonnes a year (FAO 1997). With recorded world landings from marine fisheries being in the order of 83 million tonnes (FAO 1996), discarding represents approximately one quarter of the total catch taken.

The significance of the apparent waste of fish arising from discarding has increased with the realisation that the majority of world fisheries are either fully or overexploited. FAO (1993) suggest that 13 of the 17 major global fisheries were depleted or are in serious decline. Although total world production of fisheries products continues to rise, reaching a peak of 110 million tonnes in 1994, the proportion of wild fish landed for human consumption globally has decreased from around 70 million tonnes to 63 million tonnes between 1989 and 1993 (FAO 1996, CEMARE 1996) with the difference being made up by increased landings of fish for reduction (i.e. non-human consumption) and aquaculture. In the case of aquaculture, the highest growth rates have been in high valued species such as salmon, trout, tilapia and shrimp. Overexploitation of wild fish stocks has caused particular concern for the availability of fish to large numbers of poorer consumers in developing countries to whom fish is a major source of their animal protein supplies (FAO 1997). These consumers are often unable to afford the relatively high valued farmed species.

The practice of discarding, however, is not new. References to discarding date back to at least biblical times (Alverson *et al* 1994, Corey and Williams 1995)[1]. Hence, historically the taking and discarding of unwanted fish was part of the process of getting marketable fish to shore (Corey and Williams 1995) and is not just a modern phenomenon relating to fishing technology.

The recent negative attention on discarding is largely a result of increased publicity of the problem by three groups over the last decade. First, the increased attention of conservation and environmental groups arising from concern over the effects of fishing on marine mammals, birds and turtles (Alverson *et al* 1994, Alverson and Hughes 1995) has brought the environmental effects of fishing to the attention of the general public. Increased concern for environmental issues has seen green issues take an increasingly important role in public policy formulation in many economically advanced countries.

---

1 "... like a net that was thrown into the sea and caught fish of every kind. When it was full, they drew it ashore and put the good into baskets but threw out the bad" (Matthew 13:47-48).

Conservation groups such as Greenpeace have become proactive in the call for global fisheries reform, with bycatch and discard reduction a key element (Romine 1995).

Second, as mentioned above, the decline in landings of fish for human consumption and the realisation that most world fisheries are overexploited has attracted the attention of humanitarian groups concerned for the welfare for developing countries. FAO has projected a growing gap between supply and demand for fisheries products as a result of population growth and the decline in world fish stocks respectively. At the same time, large wastages of fisheries resources are being observed from discarding unwanted catches at sea (FAO 1997).

A third group that have brought discarding to the general attention of the public are the fishers and fishers' organisations themselves. This has largely been in response to the growing implementation of fisheries management policies that have restricted their fishing activities. In a number of cases, these management policies have increased the amount of commercially valuable catch that is being discarded. These have included both input controls and output controls, although the latter have attracted significantly more attention. Minimum landing sizes result in fishers having to discard undersized fish while limits on catches through quotas results in over-quota catch also having to be discarded. Opponents to these policies have generally highlighted their effects on discarding as a lever to influence fishery policy formulation. Ironically, many of these measures have been introduced to protect fish stocks from further decline.

With the advent of increasing public concern about the level of discarding in commercial fisheries, many governments have incorporated discard reduction as a key element of their fisheries policies. For example, in the USA, the Magnuson Act (the Fisheries Conservation and Management Act of 1976, Public Law 94-265, 90 Stat. 331, 16 *US Code* 1801-1882) specifies bycatch minimisation as a key objective of conservation and management measures (section 106.9). In Norway, discarding has been prohibited (Olsen 1995). Bycatch management programmes are integral components of the quota management systems implemented in Australia and New Zealand (Baulch and Pascoe 1994).

The need to minimise discarding has also attracted significant attention at the international level. The development of sustainable fishing practices was a feature of both the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, and the International Conference on Responsible Fishing held in Cancun, Mexico, May 1992 (Everett 1997). The 'Code of Conduct for Responsible Fisheries', the development of which was recommended at the latter conference, was adopted unanimously by the 28th Session of the FAO Conference on 31 October 1995 (Everett 1997). The reduction in the level of discards in commercial fisheries is a crucial requirement in this Code. The need to minimise waste, discards, and catches of non-target species is also an integral part of the Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks (Everett 1995). Similarly, the minimisation of waste in fisheries is one of the objectives of the 1996 World Food Summit Plan of Action to optimise the long term sustainable contribution of fisheries resources to food security (Clucas 1997a).

Measures to reduce world wide bycatch of marine mammals and other endangered species have also been undertaken unilaterally by the USA. Strict controls are placed on a number of US fisheries in order to reduce the incidental catch and subsequent death of a number of protected species. Imports of fish products from similar fisheries in other countries that may have incidental catches of turtles or marine mammals are also banned unless the countries can demonstrate that they have conservation programmes and bycatch rates comparable to the US (Dilday 1994). These bans have largely impinged on shrimp and tuna fisheries.

Management measures to reduce discarding have generally focused on technical solutions. These include measures such as minimum mesh sizes and bycatch reduction devices attached to the nets. However, fisheries management in general is changing in recognition of the importance of economic factors on the behaviour of fishers. Management policies change the economic incentives faced by fishers by changing either their costs of production or the prices received. Since fishers' discarding behaviour is a rational response to the set of economic incentives they face, it is therefore possible to influence this behaviour through changing the economic incentives facing them.

The purpose in this study is to examine the economic management options for reducing discarding in commercial fisheries. The focus of the report will be to examine the incentives faced by fishers to discard or land fish. The effects of management policies on these incentives will also be discussed. The paper will draw on microeconomic theory as well as bioeconomic analyses to review the causes of discarding and the effects of policies to reduce discarding. The paper will also address the question as to what is an undesirable level of discarding.

The paper will first review the various types of discarding as well as the scope of the apparent problem and biological and economic effects of discarding. Subsequent sections will examine the economic theory underlying discards and the definition of an 'optimal' level of discards. The effect of different management systems on discards will further be assessed in the light of the economic theory. Technical and economic management options will also be considered.

2. Bycatch and discarding - an overview of the problem

Bycatch is a common feature of nearly all commercial fisheries, both industrial and artisanal. In a large number of fisheries, all or most of the bycatch may be discarded. As noted in the previous chapter, the practice of discarding dates back to biblical times. However, the importance of the discarding issue has grown in prominence with the increased level of intervention in the fishing industry through fisheries management and the increasing awareness that the resources of the oceans are not infinite.

The purpose in this chapter is to discuss definitions and key concepts relating to the practice of discarding. The extent and impact of the problem (both environmental and economic) will also be reviewed, building on the earlier review by Alverson *et al* (1994).

2.1 Definitions and concepts

Despite the fishing industries' long association with bycatch and discarding, there is still confusion over the concepts, in particular, the distinction between the concepts of bycatch and discarding. The study by Alverson *et al* (1994) found that the term 'bycatch' had been used to identify (1) species retained and sold, (2) species or sizes and sexes of species discarded as a result of economic, legal or personal considerations, and (3) non-target species retained and sold, plus all discards (Alverson *et al* 1994, p5).

Hence, there is considerable confusion between bycatch and discarding in the popular and academic fisheries literature. In many cases, the two are considered to be synonymous. The purpose of this section is to define key terms and concepts used in the study. Alternative interpretations are also presented where possible.

2.1.1 Bycatch and discards

The fish stock is part of a marine ecosystem that is multispecies in nature. That is, a number of different fish species occupy the same habitat (the physical space in the seas and oceans). Fish in this sense is used as the generic term for all marine animal life (excluding marine mammals). Hence, the term fish represents shellfish and crustaceans (i.e. shrimp, crabs and lobsters) as well as fin fish. Some of these fish may have commercial value while others do not.

Applying fishing effort to the marine habitat will result in a combination of these species being caught. In most cases, fishers will be primarily interested in catching only one or two of the species caught – the target species. The other species, whether commercially valuable or not, are bycatch. Hence, bycatch is the unintended catch taken while targeting particular species (Alverson *et al* 1994, Corey and Williams 1995, Newton 1995, Romine 1995, Smith 1995a). Other terms for bycatch used in this context include 'by-product' and 'joint catch' (Alverson *et al* 1994).

In contrast, Section 102(a) of the Magnuson Act defines bycatch as fish which are harvested in a fishery, but which are not sold or kept for personal use. In this case, bycatch is interpreted as the unwanted catch. From this definition, all retained catch would be considered targeted catch while all discarded catch would be considered bycatch.

The Magnuson Act defined only two types of discards – economic discards and regulatory discards. Economic discards refer to fish that are the target of a fishery, but which are not retained because they are of an undesirable size, sex or quality, or for other economic reasons (Section 102.9). Regulatory discards refer to fish that are caught but are required by regulation to be discarded, or are required by regulation to be retained but not to be sold (Section 102.33). Under these definitions, fish that are discarded because they have no commercial value and are not explicitly targeted are not considered discards.

From these definitions, bycatch consists only of catch that has no commercial value. However, discards consist only of catch that has commercial value but is not retained. Consequently, discards do not relate to bycatch under the definitions of the Magnuson Act.

Other sources prefer to avoid the confusion by referring to catch as either retained or discarded. Retained catch can be further subdivided into either target or incidental catch (FAO 1997). Under such a definition, a species can move from one group to another depending on size, market demand or regulations imposed by management.

For the purposes of this report, bycatch will be taken to mean the incidental catch of fish that is taken when targeting a particular type of fish. The incidental catch may be defined as comprising non-target species and undesirable sizes or sex of the target species. An incidental species may be considered as bycatch in one fishery but a target in another fishery. The incidental species may have market value or no market value. The incidental catch may be either retained or discarded.

This definition of bycatch can be expanded to include species other than fish. As will be discussed in subsequent sections of the chapter, unintended catch of birds and marine mammals are also a features of some fishing activities.

2.1.2 Target and bycatch species

A species is said to be targeted if fishing is undertaken with the explicit intention of catching it. For example, shrimp trawlers target shrimps, although they catch a wide variety of other species in the pursuit of shrimps. The unintended or incidental catch is termed the bycatch. The bycatch species in one fishery may be target species of other fisheries. Hence, the definition of a target species is fishery specific.

In many multispecies fisheries, the ability of fishers to target individual species is limited. As a result, the application of effort to a particular area could result in a variety of species being caught. Such a fishery is generally termed a mixed species fishery, as a mixture of species are caught (Clark 1985). The difference between a multispecies fishery and a mixed species fishery is subtle, and most studies do not distinguish between the two. As assumed in the previous section, it is possible in some multispecies fisheries to target individual species. The ability of fishers to target individual species and the resultant mix of species harvested will depend on the type of gear used and the time or area fished (Newton 1995). A mixed species fishery is a multispecies fishery where the ability to target individual species is limited, resulting in a mixture of species being caught. In most cases, the terms multispecies fishery can be used to describe a mixed fishery.

An example of a mixed fishery is the English Channel fishery (ICES areas VIId and VIIe). This fishery consists of a wide variety of fishing activities that are aimed at targeting a variety of species. Over 100 species have been recorded in the catch in the fishery, with over 50 species having commercial significance. The distribution of species in the catch of the fishery is a function of the fishing gear used, the area fished, and the season fished.

Table 2.1 Average recorded landings per day by UK boats along the English Channel, 1992.

Species	Fishing gear				
	Otter trawl (kg/day)	Beam trawl (kg/day)	Gill nets (kg/day)	Pots (kg/day)	Line (kg/day)
Angler fish	9	36	26	-	2
Bass	2	1	6	-	3
Bream	6	2	-	-	-
Brill	1	14	1	-	-
Cod	21	12	29	-	6
Gurnard	7	18	-	-	-
Hake	4	3	48	-	1
John Dory	2	1	-	-	-
Lemon sole	28	23	-	-	-
Ling	2	4	29	-	45
Mackerel	6	5	3	-	167
Megrims	3	22	-	-	-
Plaice	51	186	20	-	-
Pollack	17	3	36	-	28
Skate	12	18	12	-	2
Sole	6	102	6	-	-
Turbot	1	8	2	-	1
Whiting	58	9	5	-	1
Cuttlefish	9	63	1	-	-
Squid	19	7	-	-	-
Scallops	-	8	-	-	-
Lobster	-	-	-	5	-
Crabs	-	-	4	572	-
Other species	64	79	25	6	58
Total catch	330	624	254	584	315

Source: UK Ministry of Agriculture, Fisheries and Food

For some gear types, the concept of target and bycatch species is unclear. For example, UK otter trawlers take a wide variety of species with no identifiable target species (Table 2.1). The concept of bycatch in this case is not clear, as there is no clear distinction between bycatch and target species. In other parts of the fishery, some species are more economically desirable than others in the catch, and it may be the combination of these species that form the target of the fishing effort. For example, beam trawlers target both sole and plaice, yet these species make up less than half the retained catch by weight. In contrast, some gear types are able to target specific species. For example, fishers using pots take a narrow range of species, targeting crab and lobster.

The ability to target an individual species is a function of the selectivity of the gear and the behaviour of the fish species. The selectivity of the gear is a function of the characteristics of the gear itself. Different types of gear are more suitable for targeting different types of fish species (Table 2.2). For example, the mesh size of trawl nets determines the size of fish caught. All fish that are within the size range susceptible to the gear will be caught if they are in the path of the gear. As bottom trawl nets are often dragged along the sea floor, catches of pelagic species (species that spend most of their life near the surface such as mackerel) are generally small. Similarly, fish that occupy rocky grounds (such as crabs and lobster) are generally less vulnerable to trawling as fishers try to avoid these grounds to reduce damage to their nets. In contrast, pots are able to be placed on rocky ground. The bait used in the pots attract the crabs and lobsters, but generally do not attract many other species. Hence, as seen in Table 2.1, bycatch of different species is generally less in pot based fisheries than fisheries that use less selective gear such as trawls.

Table 2.2 Methods of fishing used for different Australian target species

Target species	Methods of fishing	Examples of fish targeted
Shark	gillnets	school, gummy and tropical
	longlines and hooks	mainly school and tropical sharks
Demersal fish species	trawl nets	redfish, flathead, orange roughy
	danish seine	redfish, flathead, whiting
	dropline	trevalla
Pelagic fish species	purse seine	pilchards, jack mackerel, skipjack tuna
	longlines	southern bluefin tuna, yellowfin and bigeye tunas
	pole and line	southern bluefin tuna, yellowfin and skipjack tuna
Crustaceans	pots	lobsters, crabs
	trawls	prawns
	diving	tropical lobsters
Molluscs	jigging	squid
	trawl/dredge	scallops
	diving	pearls, abalone

Source: Newton and Causbrook (1995)

For many mixed fisheries such as the English Channel, the distinction between bycatch and target species is not clear. In these fisheries, the existence of bycatch is not a problem *per se*, but becomes a problem when restrictions are placed on the catch of individual species, as will be discussed in subsequent chapters.

For other fisheries, the ability to target specific species is high. For example, pole and line tuna fisheries in South Australia catch only tuna (southern bluefin, yellowfin and skipjack tuna) with zero bycatch. The boats are able to position themselves directly on top of the school and the tuna are brought into a feeding frenzy using small bait fish (Newton and Causbrook 1995). The tuna are caught using a line with unbaited hook attached to a pole. While dolphins are often associated with schools of tuna (and have caused problems in tuna fisheries using purse seines and other fishing techniques) these do not take the hook.

While longline fisheries are usually considered to be relatively free of bycatch, these fisheries can also have important bycatch problems (Dayton, Thrush, Agardy and Hofman 1995). These include both commercial species and non-commercial species (e.g. seabirds and turtles).

2.1.3 Size and sex considerations

The concept of bycatch also applies to different sizes and sexes of the same species. The most basic form of management that is applied to most species is a minimum size limit. These restrictions are often imposed to deter fishers from targeting juvenile fish and hence allow these fish to grow to a size where they are able to reproduce. While trawl or gillnet mesh sizes can be regulated in order to reduce the catch of juvenile fish, other fishing gear (such as standard crab pots) are not size selective. In many cases, trawl mesh is not perfectly size selected and a number of small fish end up in the catch. Undersized fish must be returned to the sea or the fisher faces prosecution. Mortality of discards of undersized fish caught by trawlers are generally high.

For a number of species, the smaller size grades do not have a market. This happens, for example, with small haddock in many EU markets. Small haddock is not demanded by processors, and the fresh fish market is only able to clear a small quantity of small haddock at or above the minimum price. As a result, considerable quantities are withdrawn from the market under the price support provisions of the Common Fisheries Policy. In the absence of the EU price support mechanisms (i.e. a subsidy) most of this catch would be considered bycatch and most likely discarded.

Similar discarding of small commercial species has been observed in the Australian South East Fishery. Even prior to the introduction of individual transferable quotas, large quantities of small redfish were being discarded as the price received was too low to warrant marketing (Baulch and Pascoe 1992). Again, catch of these size classes would be considered bycatch even though larger fish of the same species is targeted in the fishery.

The sex of the fish is also an important factor in the level of discards. In some fisheries (particularly crab and lobster fisheries), there is a ban on taking females, especially if they are carrying roe. Pots are not sex specific, so catch of females is an unintended bycatch associated with the catch of males. Similarly, while escape panels can be built into the pot to allow small shellfish to exit, if the fish is in the pot when it is raised it will be caught even if it could have (and most likely would have) exited the pot had it not be lifted at that point in time.

An example of the potential scope of the sex-size bycatch problem is the Bering Sea fishery. Bering Sea crab fishers discarded almost 6 crabs for every crab retained in 1992 (Stevens 1995). However, unlike finfish discarded after capture using trawl gear, discards of crabs and lobsters from pots are more likely to survive. Consequently, while a significant number of shellfish may be discarded, the waste associated with this discarding may be minimal.

Discarding undersized, oversized or female lobsters is also a common occurrence in the Western Australian Rock Lobster Fishery (Western Australian Department of Fisheries 1996). Again, mortality rates from these discards are low so the effects of discarding on the fishery is likely to be minimal.

2.1.4 Other bycatch/discarding

A third form of discarding is of part of the fish that has little or no commercial value. An example that has attracted world-wide attention from environmental groups is the practice of 'finning' of sharks. This involves cutting the fins off sharks and discarding the main body. In most cases, the sharks themselves are incidental bycatch associated with longlining or driftnetting for tuna.

The roe or gonads of a number of species are also highly valued while the body is not. For example, sea urchins are harvested to extract the gonads. These are considered a delicacy in many eastern countries. The remainder of the animal is discarded as it has no commercial value. Similarly, mass discarding of salmon carcasses have been observed recently in Alaska. The roe, which attracts a high price on the Japanese market had been extracted and the carcasses, which attracted a low price at the time, were discarded.

While the target of the fishing activity in these cases is the body parts that attract the high prices, these cannot be taken without capture and killing of the whole animal.

Fish are also discarded if they are damaged or have no commercial value in their own right. For example, many fish species caught with prawn trawlers in the Australian northern prawn fishery have no market value and are consequently discarded (Pender, Willing and Cann 1992).

Some fisheries management policies can also result in fish with commercial value being discarded. Minimum size restrictions may result in small fish being discarded while quotas may result in over-quota catch being discarded. The effects of such policies on the level of discarding are further examined in the following chapters.

2.1.5 Fate of targeted and incidental catch

From the previous section, it can be seen that fish can be discarded for a range of reasons. The same fates are applicable to both target and bycatch species. The potential fate of fish once caught is illustrated in Figure 2.1. Once caught, a fish can either be retained and sold on the legitimate market, retained and sold on the black market or discarded. As outlined above and as will be further discussed in subsequent chapters, there are circumstances in which fishers will discard even fish that have a commercial value. While the reasons for discarding such fish are largely management induced (e.g. due to a quota constraint), such discarding can take place in unmanaged fisheries (e.g. due to a hold constraint). In most cases, fish that is non-marketable because it is either damaged or is a non-commercial species is discarded. Fish that are illegal to land (due to restrictions imposed by fisheries management) are in most cases discarded, although some of this fish may be sold on the black market.

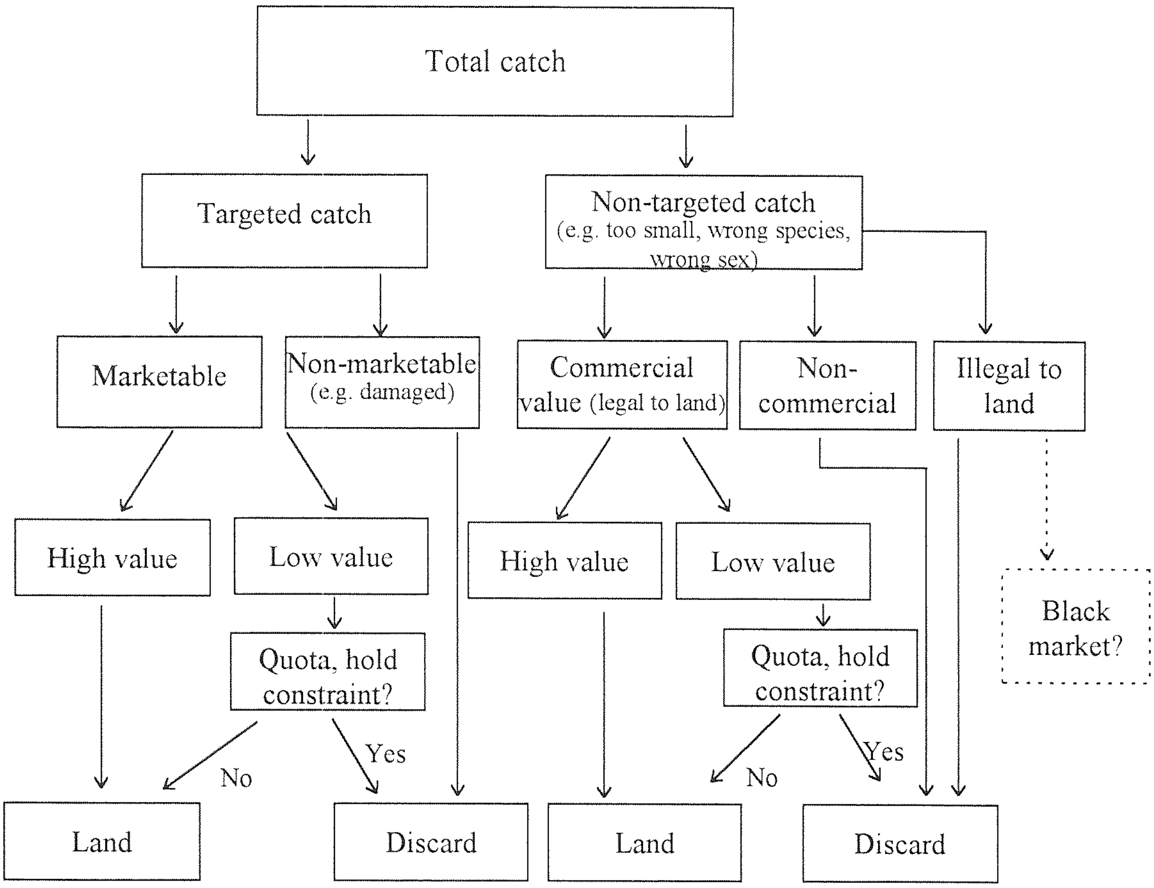


Figure 2.1 Allocation of total catch into landings and discards

Apart from concerns about food supplies, the key problem caused by discarding in most fisheries is that the catches are not recorded. Discarded catch and catch landed illegally generally does not appear in any official statistics. Factoring this catch into estimates of fishing mortality is a major problem for many fisheries scientists. Hence, the relationship between targeted catch and bycatch is important when formulating management plans and these can be factored in provided the relationship is known. This knowledge will depend on the proportion of catch retained and discarded, as well as the monitoring programme that is in place to collect information on total catches of each species.

2.2 Magnitude of discarding

As stated earlier, a recent study of bycatch and discarding estimated that between 17.9 and 39.5 million tonnes of fish are discarded annually from commercial fisheries (Alverson *et al* 1994) representing approximately one quarter of the total catch taken and one third of the catch taken for human consumption. Alverson *et al* (1994) suggested that the best estimate of total discards was around 27 million tonnes based on data over the 1980s and early 1990s. This figure is significantly higher than previous estimates from the early 1980s which estimated global discarding to be around 6.7 million tonnes (Saila 1983).

The apparent increase in the level of global discarding may be more a function of the increased level of data on discarding rather than increased discarding *per se* (Alverson *et al* 1994). Available data for 1994-95 suggest that the level of discarding has decreased since the mid 1980s due to a number of factors (FAO 1997). These include a decline in the level of fishing, greater use of more selective gear, greater utilisation for human consumption and a more progressive attitude of fisheries managers and fishers to solving the problems of discarding (FAO 1997). Based on these factors, it is now expected that annual discards are at the lower end of the range suggested by Alverson *et al* (1994), and are most likely to be in the order of about 20 million tonnes annually (FAO 1997). This notwithstanding, discarding still accounts for a significant proportion of total catch.

2.2.1 Discards by fishing method and region

The level of discards varies by fishing technique, target species and area fished (Table 2.3). Pacific Ocean fisheries account for about 58 per cent of total discards with the Northwest Pacific contributing one third of the total global discards (Table 2.4). Key fisheries in this region contributing to the discarding were shrimp, crab, mackerel, Alaska pollock and cod fisheries (Alverson *et al* 1994).

Demersal trawling gear (including both shrimp trawl and other non-pelagic fish trawl) in general was associated with substantially higher discard rates (that is, the amount of catch discarded in relation to the amount of catch retained) than most other fishing gear (Table 2.3). As stated above, demersal trawl gear is generally not species selective. While mesh size can influence the minimum size of fish caught, size selectivity is based on the minimum size of the target species. For example, shrimp nets generally have small mesh sizes in order to catch the small (relative to most finfish species) shrimp. As a result, shrimp fishers generally catch a wide variety of other species.

Table 2.3 Discard ratios by gear type, area and target species

Gear type	Area	Target species	Discard ratio[a]
Shrimp/prawn trawl	Trinidad	Penaeid shrimp/prawns	14.71
	Indonesia	shrimp/prawns	12.01
	Gulf of Carpentaria (Aust.)	banana and tiger prawns	11.10
	Other recorded areas	shrimp/prawns	≤ 11.00
Demersal fish trawl	Northwest Atlantic	finfish	5.28
	Bering Sea	rock sole	2.61
	British Columbia	Pacific cod	2.21
	Other areas	-	≤ 2.10
Danish Seiner	Northeast Atlantic	haddock, whiting, cod	0.36-0.50
Pelagic fish trawls	All recorded areas	cod, pollack	≤ 0.01
Longline	Bearing Sea	Greenland turbot	1.13
	Eastern Central Pacific	swordfish	1.00
	Other recorded areas		≤ 0.50
Purse Seine	Northwest Atlantic	capelin	0.37-0.81
	Other recorded areas	sardines, tunas	≤ 0.03
Fish Trap	Bearing Sea	sablefish	3.51
	Northwest Atlantic	capelin	0.80
Pots	Bearing Sea	tanner, king crabs	1.78-3.39
	East Central Pacific	spiny lobster	0.36

a) Amount of catch (kg) discarded for each kg of catch retained. Source: Alverson *et al* (1994)

Table 2.4 Discards from shrimp and other fisheries by region

Ocean	Area	Source of discards		
		Shrimp fisheries '000 tonnes	Other fisheries '000 tonnes	Total discards '000 tonnes
Atlantic	Northeast	206.1	3465.3	3671.3
	West Central	1271.3	329.6	1600.9
	Southwest	245.8	557.0	802.9
	Northwest	80.0	605.9	685.9
	East Central	61.8	532.4	594.2
	Southeast	19.6	258.2	277.7
	Antarctic	-	35.1	35.1
Pacific	Northwest	4155.9	4975.8	9131.8
	West Central	1377.8	1398.9	2776.7
	Southeast	197.6	2404.1	2601.6
	Northeast	27.4	897.4	924.8
	East Central	561.4	206.0	767.4
	Southwest	18.9	274.5	293.4
	Antarctic	-	0.1	0.1
Indian	Western	748.4	722.8	1471.3
	Eastern	289.7	512.5	802.2
	Antarctic	-	10.0	10.0
Mediterranean/Black Sea		250.1	314.5	564.6
Total		9512.0	17500.1	27012.1

Source: Alverson *et al* (1994)

The proportion of unintended catch in shrimp fisheries is generally large as a result of the relatively small mesh size. Consequently the highest discard ratios were observed in the shrimp fisheries. Over one third of the estimated total global discarding was from shrimp fisheries (Table 2.4). In the west central Atlantic Ocean, shrimp fisheries were responsible for almost 80 percent of the total discards (Figure 2.2).

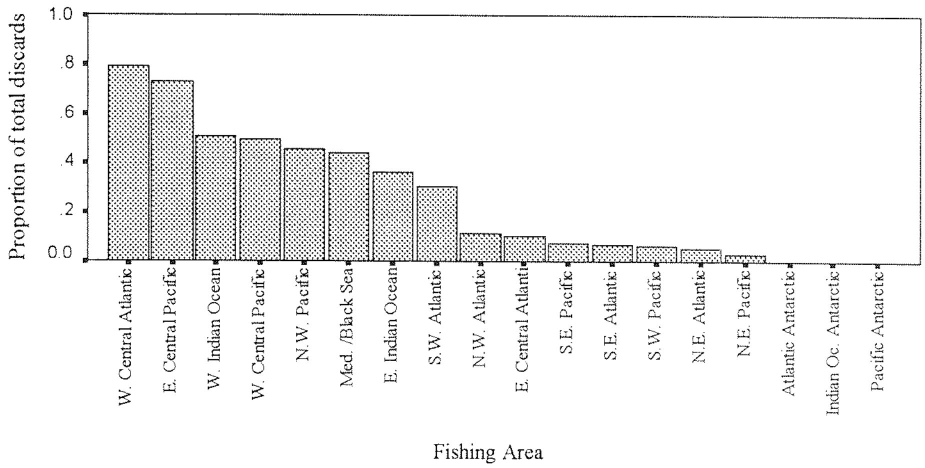


Figure 2.2 Proportion of total discards from shrimp fisheries

On average, Alverson *et al* (1994) estimated that 5.2 kg of bycatch were discarded for every kilogram of shrimps landed, with discard ratios of nearly 15:1 observed is some fisheries (Table 2.3). Other studies have suggested that discard ratios relating to shrimp fisheries are highly variable. For example, discard ratios ranging between 2 and 130 (average 19.5) have been reported in Brazil (Dragovich and Villegas 1983) and between 3 and 136 in the South Carolina offshore shrimp fishery (Keiser 1976).

High discard rates are not experienced in all shrimp fisheries. Liggins and Kennelly (1996) estimated discard ratios of between 0.13 and 0.45 in the Clarence river prawn fishery. As similar ratios were found using other gear (set pocket nets) in the same area (Andrew *et al* 1995), it is likely that the species composition of the area fished is an important factor in influencing bycatch ratios.

The discards from shrimp fisheries consist largely of finfish and other crustaceans. In some cases, such as in the Australian northern prawn fishery, some of the bycatch that is discarded is of commercial species that could be readily sold on the market (Pender, Willing and Cann 1992). However, the price that could be potentially received is substantially lower than that of the target species and not considered sufficient to justify the costs associated with handling the fish[2]. Less than 5 per cent of the bycatch was retained, this consisting of high valued bycatch species only that were readily accepted on the Australian market (Pender, Willing and Cann 1992).

An assessment of the commercial value of bycatch in the North Carolina and south east shrimp fishery found that, although consisting of commercial species, landing shrimp

[2] The rationale for discarding lower valued commercial species will be discussed in the following chapter.

bycatch was generally not commercially viable. This was because few dealers were prepared to handle and ship the incidental finfish catch. Also, the expected price was not worth the effort as additional costs would be incurred (e.g. ice), space would need to be provided and separating out the finfish catch delayed icing of the more valuable shrimp (Murray, Bahen and Rulifson 1992).

In many other shrimp fisheries, the bycatch consists of juvenile species that could be harvested by other fisheries at a later date (Liggins and Kennelly 1996) or by other commercial or recreational fishers. For example, in the Gulf of Mexico, adult red snapper are harvested by commercial and recreational fishers. However, mortality rates of juvenile red snapper are as high as 75 per cent in the shrimp fishery (Hendrickson and Griffin 1993).

While pots may be more selective than trawls, the proportion of total catch discarded in crab fisheries was second only to the discards from shrimp fisheries (Table 2.5). As mentioned previously, however, most of these discards are most likely undersized crabs or females with roe. The survival of these discards is likely to be high.

Table 2.5 Proportion of total catch discarded by target species

Target species	Proportion of total catch discarded %
Shrimp, prawns	84
Crabs	71
Eels	46
Flatfish (Founders, Halibuts, Soles)	43
Redfishes, basses, congers	39
Lobsters, spiny rock lobsters	35
Jacks, mullets, sauries	22
Cods, hakes, haddocks	17
Tunas, bonitos, billfishes	15
Herrings, sardines, anchovies	10
Shads	9
Squids, cuttlefish, octopuses	8
Salmons, trouts, smelts	5
Mackerels, snooks, cutlassfishes	3
Other marine fishes	9
Weighted average over all species	26

Source: Alverson *et al* (1994)

By comparison fishing gears targeting pelagic species (pelagic trawling gear and purse seine) were estimated to have some of the lowest discard ratios of all gear types for which data were available (Table 2.3, Table 2.5). Pelagic species tend to aggregate away from other species and hence the mix of species is limited. As a result, only about 15 per cent of the catch is discarded. Pelagic gear, however, is more susceptible to bycatch of marine mammals and seabirds, as will be discussed below.

2.2.2 Marine mammals, turtles and seabirds

While the focus of this report is on the discards of potentially commercial fish species, a report on bycatch and discards would not be complete without reference to incidental catch of marine mammals[3] and other air breathing animal species. These are especially important since much of the attention given to reducing bycatch originated in the problems of incidental catch of these species.

Despite greater environmental interest in the protection of marine mammals, estimates of the total bycatch of air-breathing animals is even more speculative than that of many commercial fish and shellfish due to the lack of information on the quantity of discards. One estimate of total cetacean mortality is between 65,000 and 86,000 animals a year (Alverson *et al* 1994). In addition to this are large numbers of seals, turtles and seabirds that are also caught as bycatch.

Considerable attention has been paid by conservation groups to the use of drift nets on the high seas as well as in territorial waters. Much of the controversy has focused on the activities of Japanese and Taiwanese boats fishing for tuna in the south Pacific. However, estimates of bycatch in this area is poorly documented (Northridge 1991). One estimate for the Tasman Sea was 56 dolphins for each 1000 km of net, resulting in about 4,600 dolphins being caught each year (Coffey and Grace 1990 cited in Northridge 1991).

Driftnetting in the north Pacific for salmon and tuna has also come under severe criticism as a result of the large incidental catch of porpoises, seals and seabirds. Northridge (1991) estimated that between 700 and 1200 Dall's porpoises were caught in 1987 in the offshore salmon driftnet fishery[4] and a further 800 to 1,400 in the land based fishery. In addition, between 400 and 100 fur seals were estimated to be taken each year along with 23 species of seabirds (Northridge 1991).

The high mortality of air breathing animals has resulted in substantial pressure from environmental groups to ban driftnetting in the high seas and reduce it in territorial waters. This has largely been successful, and limits on nets have been imposed in most fisheries. As a result, current levels of bycatch associated with this fishing practice is likely to be substantially lower than in the periods referred to above.

Considerable dolphin bycatch is also estimated to occur in purse seine fisheries, particularly in the Eastern Tropical Pacific tuna fisheries. In 1989, dolphin mortality in the fishery was estimated to be around 100,000 animals (Alverson *et al* 1994). Again, current mortality rates are expected to be lower than this as methods have been introduced in purse seine fisheries to reduce dolphin mortality.

---

[3] While some marine mammals have a commercial value in some countries, in most countries they are considered non-commercial species. These species may, however, have a passive use value, as will be discussed in Chapter 4.

[4] Catches of porpoises in 1987 were substantially lower than in previous years, where catches over 3000 a year (and in one year almost 6000) were more common.

Significant quantities of seals are also caught annually in both passive gear (e.g. gillnets and drift nets) as well as mobile gear (trawls) (Wickens 1995). However, there is insufficient information to make an overall estimate of seal mortality (Alverson *et al* 1994). There have been a number of studies of individual fisheries that can provide an indication of the magnitude of the problem. An example of seal mortality in driftnet fisheries has already been presented above. Seal mortality varies considerably depending on the gear type and area fished. For example, incidental mortalities of Californian sea lions are estimated to be in the order of 2,000 to 3,000 a year in the set net fisheries of Washington, Oregon and California with a further 1,000-2,000 harbour seals also being caught in California (Barlow *et al* 1990). In many other fisheries, however, such as the Barents Sea trawl fishery, seal bycatch is in the order of one or two a year (Wickens 1995).

Bycatch of turtles has been a problem in several shrimp fisheries around the world. In the late 1980s, between 5,000 and 50,000 turtles were caught annually in the shrimp fisheries in the south-eastern USA with mortality rates of around 20 per cent (Henwood and Stuntz 1987)[5]. In the Australian northern prawn fishery, around 5,700 turtles were caught each year with an estimated mortality of between 6 and 10 per cent (Poiner and Harris 1994). Similar catches (around 5,300 turtles a year) are estimated for the prawn fisheries along the Queensland east coast, over half of which were caught off the southern waters in Morton Bay (Robins 1995). Mortality rates for these turtles were considerably lower than in the other two fisheries - around 1.1 per cent (Robins 1995).

Turtles have also been recorded as bycatch in ocean longline fisheries, with annual catches estimated to be in the order of 40,000 world-wide (Alverson *et al* 1994). Mortality rates for this bycatch has been estimated to be as high as 42 per cent (Nishemura and Nakahigashi 1990 cited in Alverson *et al* 1994)

Seabirds are also a bycatch species in some fisheries. In 1977, between 113,000 and 232,000 seabirds were caught in the land based salmon driftnet fishery in the North Pacific (Sano 1978 cited in Northridge 1991) while between 130,000 and 180,000 seabirds were estimated to be caught by the offshore fishery between 1977 and 1981 (Ogi 1984 cited in Northridge 1991). In 1989, about 44,000 albatross were killed by Japanese tuna longline boats operating in the Southern Ocean (Newton and Truelove 1995).

---

[5] Alverson *et al* (1994) reports a substantially higher estimate of turtle mortality in the same area at the same time. The higher estimate is that as many as 55,000 turtles may have drowned annually in the shrimp fisheries of south-eastern USA and the Gulf of Mexico. Assuming similar mortality rates as those reported by Henwood and Stutz (1987), then as many as 275,000 turtles may have been caught annually in the shrimp nets.

2.3 Impact of discards

Of more importance than the magnitude of discarding is the impact of discarding on the fisheries population, the environment and/or other fishers. Hall (1995a) developed a classification of bycatch based on the type of impact. This classification system, based on seven categories of bycatch, equally applies to discards:

- *Critical bycatches*: bycatches of populations or species that are in danger of extinction;
- *Non-sustainable bycatches*: bycatches that are depleting the stock (that is, removals are exceeding natural growth of the stock), but have not driven the stock to critical level with risk of extinction;
- *Sustainable bycatches*: bycatches that do not result in population decline (that is, removals are less than the natural growth of the stock);
- *Biologically insignificant bycatches*: bycatches that are so low as to be considered negligible from the point of view of the dynamics of the fishery;
- *Bycatches of unknown impact*: bycatch were the data is insufficient to determine the effects on the stock;
- *Ecosystem level impacts*: the removal of the bycatch is causing alterations in the ecosystem (e.g. removal of prey species affects predator species); and
- *Charismatic bycatches (taboos)*: bycatches of species that have special value to society, and that value may be independent of the level of impact of the bycatch on the existence of the species. Examples of this groups may include bycatch of turtles, dolphins and other marine mammals.

The classification system of Hall (1995a) is basically concerned with the environmental impact of bycatch and discarding. To this list can also be added another category of bycatch:

- *Inter-fishery bycatch*: bycatch in one fishery that affects the catches of fishers in other fisheries. This is an economic impact rather than biological impact.

While the classification system of Hall (1995a) was primarily aimed at bycatch in general, the high mortality rate of discards suggests that a similar classification can apply to discarding. In this section, the environmental and economic impacts of discarding will be examined.

2.3.1 Environmental impacts of discarding

Discarding can have both positive and negative effects on the environment. These effects vary from fishery to fishery. The main negative effect of discarding occurs as a result of the death of the animal discarded. In many cases discarded fish, particularly from trawl fisheries, do not survive. Depending on the level of discards, this may have an impact on the population of these species. In such a case the bycatch and discards would be considered critical or non-sustainable in the above nomenclature. In contrast, discarded fish may be used as a food source for other species. This could be considered a beneficial effect, particularly if the benefiting species was considered of great environmental or economic value.

The survival of the discarded fish is a function of the gear used, the length of time the fish was out of the water, the depth from which it was brought and the species itself (Berghahn, Waltemath and Rijnsdorp 1992). Animals may be injured by different parts of the fishing gear or may find different stages of the operation more stressful than others (Sangster 1994 cited in Kaiser and Spencer 1995). Finfish may be crushed in the cod end of trawl or damaged by other species spines or scales (e.g. starfish). Bringing deep water fish to the surface also causes major stress, with the decompression often causing fatal damage to swim bladders and other organs. Those that survive the journey to the surface must also face exposure to air for prolonged periods of time. This also causes major stress and is often the main cause of mortality (Kaiser and Spencer 1995).

Berghahn, Waltemath and Rijnsdorp (1992) found relatively low discard mortality rates for juvenile plaice and sole caught as shrimp fishery bycatch. However, the fish in this case were placed in tanks after capture and exposed to relatively short trawls. Hence, the results may not be transferable to commercial practices (Berghahn, Waltemath and Rijnsdorp 1992). The same study also found 100 per cent mortality of whiting caught as bycatch in the shrimp trawls, most of which were dead after sorting.

Animals returned to the water alive may also subsequently die from injuries received when trawling. A study of the North Sea nephrops fishery found that as much as 59 per cent of the catch of nephrops were damaged after a 30 minute trawl. While most of the nephrops were alive when brought to the surface, the injuries sustained were a major cause of subsequent on-board mortality (Evans, Hunter, Elizal and Wahju 1994). A substantial proportion of the discarded nephrops (70 per cent) were consumed by seabirds immediately after discarding. Those discarded nephrops that made it back to the sea bed were unable to compete with existing (uninjured) nephrops for food and shelter, further reducing their chance for survival (Evans, Hunter, Elizal and Wahju 1994). Hence, survival rate of the discarded nephrops was taken to be zero per cent (Evans, Hunter, Elizal and Wahju 1994). Given that 63 per cent of the nephrop catch by weight and 85 per cent by number (Evans, Hunter, Elizal and Wahju 1994) were being discarded, the subsequent high mortality rate of the discards may have been having a substantial negative influence on the population.

Based on the available research, mortality rates for discarded commercial fish species are generally assumed to be 100 per cent (Chopin *et al* 1995, Kaiser and Spencer 1995, Chen and Gordon 1997). Other non-commercial species are more resilient to fishing. For example, Kaiser and Spencer (1995) found that starfishes, hermit crabs and molluscs have a high survival rate (although many were damaged) after discarding from beam trawl fisheries.

A major problem created by discarding in many fisheries is not the additional fish mortality created by discarding *per se*, but that the level of discarding (and hence the associated level of fish mortality) is not recorded. Estimates of catch are usually based on landing information provided by either a sample of boats or logbook programmes (Hilborn and Walters 1992). Discarded fish represent catches that are not documented in landing statistics, but are nevertheless real removals from the stock (Chen and Gordon 1997). Hence, the absence of discarding information can result in incorrect stock assessments and incorrect management advice. This in turn could lead to problems of overexploitation of the resource (Hilborn and Walters 1992).

The impact of discarding on stock size varies considerably from species to species and region to region. In the Gulf of Main groundfish fishery, discards of undersized species has been identified as a contributing factor in population declines (Saville 1980 cited in Alverson *et al* 1994). In the Irish Sea, the decline in the stock of the common skate has been attributed to substantial quantities of the fish being taken as bycatch (Clucas 1997a).

In the Australian south east fishery, bycatches of eastern gemfish were almost responsible for placing the species on the endangered species list. The stock was largely depleted through targeted fishing and subsequently subjected to a zero total allowable catch in order to try and protect the stock from collapse. However, the gemfish were also caught as bycatch (and discarded due to the zero total allowable catch) when a number of other species in the fishery were targeted (Pascoe 1994).

Similar problems were observed with bycatch of redfish in the Northeast Atlantic. While discarding accounted for only about 2 per cent of the redfish stock biomass, the stock was at a very low level and the bycatch of redfish was thought to have impeded the stock recovery (Alverson *et al* 1994).

Discarding and bycatch can have indirect effects on the fishery resources. Incidental capture of sharks in the Northwest Atlantic swordfish fishery is thought to have resulted in a substantial increase in the seal population, which in turn has impinged on the commercial cod stocks (Dayton, Thrush, Agardy and Hofman 1995).

The impact of discarding is dependent on the state of the stock and its contribution to total fishing mortality. For some species in the Bearing Sea, discard mortality is the main source of fishing mortality. For example, discards account for about 56 per cent of total sole mortality and 83 per cent of flounder mortality (Alverson *et al* 1994). However, for both these species, total fishing mortality is sufficiently low so as to prevent overfishing of the stock. In these cases, the discards would be considered to be from biologically insignificant bycatch.

From the above, discard mortality can (but does not always have) a significant impact on the stock. The main problem facing many fisheries scientists is not the fact that discarding takes place *per se*, but that the level of discarding is not known. Further, other forms of unrecorded fishing mortality also exist that can have a detrimental effect on the stock. Total fishing mortality can be expressed by:

$$F = (F_{cl} + F_{al} + F_{rl}) + F_b + F_d + F_o + F_a + F_e + F_g + F_p + F_h$$

where $(F_{cl}, +F_{al}, +F_{rl})$ represents recorded fishing mortality (i.e. landings) from commercial, artisanal and recreational fishers respectively;

F_b illegal and mis-reported landings;
F_d discard mortality;
F_o mortality associated with fish passively dropping off or out of fishing gear;
F_a mortality associated with fish avoiding fishing gear;
F_e mortality associated with fish escaping fishing gear;
F_g mortality associated with ghost fishing;
F_p mortality associated with predation after escape; and
F_h mortality associated with habitat change.

(Chopin *et al* 1995).

In most cases it is impossible to determine the magnitude of all of these components of fishing mortality. However, a number of studies have looked at individual components of the equation. For example, Suuronen, Erickson and Orrensalo (1996) estimated that 91 per cent of small (<12 cm) herring and 62 per cent of large (12-17cm) herring would be dead 14 days after escaping from pelagic trawl cod-ends. While passing though the cod-end damaged the skin of the fish, most of the mortality was estimated to be due to skin injuries and exhaustion that occurred while the fish was in the funnelling rear part and the cod-end itself. A similar study found lower mortality rates for whiting and haddock, with between 48 and 85 per cent of whiting and 52 and 86 per cent of haddock surviving escape from the cod-end (Sangster, Lehman and Breen 1996).

Ghost fishing occurs when fishing gear is lost at sea. This gear can continue to catch fish, thereby causing a further source of unrecorded fishing mortality. Crab traps may continue to catch crabs for up to 15 years almost as effectively as active gear, while lost gillnets have been estimated to catch at a rate of about 15 per cent of the active gillnet (Laist 1995). A number of studies have estimated that ghost fishing mortality in crab fisheries may be 10-12 per cent of the active fishing mortality (Chopin *et al* 1995).

Discarding can also change the species mix in the habitat by providing an additional food source. Seabirds in particular benefit from the additional food supply provided by discards from fishing vessels. Populations of most seabirds and some coastal bird species in the North Sea have increased over the last few decades, most likely as a result of the additional food resource provided by discards (Garthe and Hüppop 1994). North Sea seabirds have been observed to consume 84 per cent of discarded roundfish and 8 per cent of discarded flatfish (Garthe and Hüppop 1994). Also, as noted earlier, about 70 per cent of discarded nephrops in the North Sea were consumed by seabirds (Evans, Hunter, Elizal and Wahju 1994). In total, as many as 5.9 million seabirds may be theoretically sustained by consuming discards from North sea fishing boats (Garthe *et al* 1996).

Similar proportions of discard fish have been observed to be consumed by seabirds following Scottish trawlers and trawlers in the German Waden Sea (Garthe and Hüppop 1994) and in the Ebro Delta and Baleric Islands (Oro and Ruiz 1997). Walter and Becker (1997) estimate that as many as 60,000 seabirds can be sustained from the discards of shrimp trawlers in the Wadden Sea.

Sharks and dolphins also benefit from discarding in some fisheries. In the Torres Strait prawn fishery birds, dolphins and sharks accounted for nearly all surface scavenging on discards (Hill and Wassenberg 1990). Both birds and dolphins were observed to follow the trawlers, associating the trawlers with a supply of food (Hill and Wassenberg 1990). Significantly fewer birds and dolphins were observed in areas that hadn't been trawled for several years (Hill and Wassenberg 1990). In the Morton Bay prawn fishery, Wassenberg and Hill (1990) estimated that one trawler operating for 10 hours could supply all the food required for 5 dolphins,

The discards that reach the sea bed may also affect the benthic species composition. Considerable portions of discards from the Australian northern prawn and Morton Bay prawn fisheries have been observed to be consumed by benthic scavengers (Wassenberg and Hill 1990, International Conference on Shrimp Bycatch 1992). These scavengers include crabs and other species. In some fisheries, the scavengers may include the shrimp themselves[6] (Sheridan *et al* 1984) so to an extent the bycatch of the fisheries may be helping to maintain the size of the shrimp stocks. In other cases, the shrimp may benefit indirectly as the discarded bycatch increases the feed available for the animals and bacteria that the shrimp depend on for their own feed (Sheridan *et al* 1984).

Similarly, discards of crabs and finfish in the Gulf of Paria, Trinidad, artisanal shrimp fishery are thought to be sustaining the population of the very crabs caught as bycatch (Maharaj and Recksiek 1991). In this case, the bycatch would be considered sustainable bycatch in the classification system of Hall (1995a).

Incidental catch has also had a benefit in some fisheries in terms of maintaining the status quo. For example, where a predator is caught as bycatch and discarded when targeting the prey species, the discarding (or even retention of the catch) helps to prevent the system becoming unbalanced. Ecosystem modelling in the Southeast shrimp fishery of the USA suggests that bycatch reductions could result in increased shrimp predation,

---

[6] This fate of discards is not common to all prawn fisheries, however. Wassenberg and Hill (1990) found no evidence of prawns consuming discards in the Morton Bay fishery.

which in turn could reduce the shrimp stocks by 10 per cent of their current level (Branstetter 1996).

2.3.2 Economic impacts of discarding

While the biological and environmental impacts of discarding have been brought to the general public's attention, discarding can also create a number of economic impacts. These impacts have had less exposure outside of the fishing industry as they are seen primarily as an internal industry problem. The economic impacts of discarding can be classified into four categories:

- Forgone income associated with discarding juvenile and adult target species;
- Inter-fishery costs associated with discarding juvenile bycatch species;
- Costs associated with discarding non-commercial species; and
- Costs associated with measuring/estimating the level of discards.

Forgone income associated with discarding juvenile and adult target species

In most fisheries, discards include a large number of commercially valuable species. These species may be discarded for a number of reasons, further details of which will be discussed in the next chapter. However, often these discards are the result of management regulations directly or the result of incentives created by fisheries management. Discarding these fish suggest an immediate economic loss to the fishers in the form of lost income. Given that survival of most species when discarded is low if not negligible, the potential to recapture these fish at a later date is minimal. Hence, the loss of revenue has been a major concern to fishers, particularly where the fish may not have been discarded in the absence of fisheries management.

Discarding juvenile fish creates costs not only for the fisher who has discarded the fish, but also for other fishers in the fishery who may have caught those fish when they had achieved a commercial size. Fishing at levels beyond maximum sustainable yield results in lower future yields, further reducing the incomes of all fishers. These future costs are not necessarily borne by the individual discarding the fish, and hence do not affect their production decision.

Alverson *et al* (1994) note several studies that have examined the loss associated with discarding commercially valuable species. These losses have ranged from $50 million in lost income in the Northwest Atlantic fishery to over $250 million annually in the Bering Sea and Gulf of Alaska. In some fisheries, Alverson *et al* (1994) hypothesise that the value of the discarded catch may approach the value of the landed catch.

While these costs may appear substantial, the foregone income associated with discarding needs to be balanced against the economic benefits of discarding. As will be discussed in more detail in subsequent chapters, the requirement to discard juvenile fish provides an economic incentive for fishers to avoid capturing these fish. Similarly, discarding over-quota fish provides an incentive for fishers to try and avoid these species or stop fishing. While there is an immediately apparent loss of income associated with the discarded fish, the income may be lower still if the fishery is overexploited and stocks decline or collapse in the future. Unfortunately, attempts to estimate these benefits have been limited (see Pascoe *et al* 1994 or Pascoe 1995 for examples).

Inter-fishery costs associated with discarding juvenile target species

Discarding can also result in costs being incurred in fisheries other than the one in which the discarding takes place. These costs, termed externalities, are not incurred by the fishers taking and discarding the bycatch and hence do not influence their production decisions. One form of externality described above is the effect of overharvesting on future yields[7]. A second form of externality resulting from discarding is the forgone value of production of other sectors of the fishing industry. These costs may result from juvenile fish being caught as bycatch in one fishery. If these fish had not been caught they could have resulted in higher yields, and consequently incomes, in other fisheries in which they may form the key target species.

Externalities are incurred in a wide range of fisheries. In the inshore shrimp fishery based in The Wash on the east coast of England, bycatch of juvenile sole and plaice are estimated to cost the target sole and plaice fishery somewhere in the order of £3.4 million a year (Revill 1997). This estimate is based on the number of sole and plaice that would have survived to harvestable age, and the proportion that would have been caught in the flatfish fishery in the absence of the shrimp fishery.

Similar problems have been experienced in the Clarence River Estuary prawn fishery (Liggins and Kennelly 1996) and the Hawkesbury River (Broadhurst and Kennelly 1994) in Australia. Bycatch and subsequent mortality of several species that are harvested by recreational and commercial fishers were recorded in both these fisheries. The economic impact, however, was not estimated due to lack of information on the mortality of the bycatch after discarding, the proportion that would naturally survive to maturity and the proportion that would be caught by other fishers if not caught by the prawn trawlers. However, the mortality of juvenile fish caught in prawn trawling in Australia has resulted in significant conflict between prawn trawl fishers and other user groups, particularly recreational fishers (Broadhurst and Kennelly 1994).

Bycatch and discarding of juvenile fish in the Gulf of Mexico shrimp fishery has resulted in some stocks being severely depleted (Hendrickson and Griffin 1993). In

---

[7] A key concept in fisheries economics is that overharvesting in general creates externalities as lower potential yields are experienced in the fishery. Each individual incurs costs created by the combined effort of all individuals in the fishery. These costs are not incorporated into the individuals' production decisions, leading to the excessive level of fishing effort (see Cunningham, Dunn and Whitmarsh 1985 or Hannesson 1993 for further details).

particular, juvenile red snapper are estimated to suffer mortality rates as high as 75 per cent, with the stock declining by 90 per cent since the 1970s (Hendrickson and Griffin 1993). While this can be considered a severe biological impact of discarding, the species (amongst other bycatch species) are targets of directed commercial and recreational fisheries. Therefore the economic impact is also likely to be considerable. The cost to these other fishers has not been quantified, although the overall value of these other (non-shrimp) fisheries is estimated to be about 55 per cent of the shrimp fishery itself. In 1991, the value of output from the finfish fishery was estimated to be about US$220 against US$410 for the shrimp fishery (Hendrickson and Griffin 1993). In the absence of the shrimp fishery and with a fully recovered stock, the finfish fishery may become significantly more valuable.

While the above examples all involve shrimp fisheries, the problem of external costs is not limited to these fisheries. Alverson *et al* (1994) note that the groundfish fishery in the Bering Sea is estimated to produce around US$150 million annual costs to halibut, crab and salmon fisheries in the area.

Costs associated with discarding non-commercial species

Discarding fish is not a costless exercise in itself. The non-commercial species have to be removed from the fishing gear in the same manner as the commercial species. For gear such as lines or gillnets, removing non-commercial species may take as much time as commercial species on a per unit basis. While this is less a problem for trawl gear (as the fish do not need to be physically detached from the gear), the non-commercial fish must still be separated from the commercial species before they can be discarded. Mechanical sorters are available to sort shrimp from finfish (Berghahn, Waltemath and Rijnsdorf 1992), although in many fisheries the separation of retained and discarded catch is undertaken manually by the crew.

Estimating the economic cost of sorting and discarding non-commercial bycatch is difficult due to problems in determining the opportunity cost of the crew's time. The opportunity cost is value of the next best alternative use of the time. In many industries, a proxy for the opportunity cost of labour can be taken as the wage rate. In most fisheries, however, the crew are paid a share of the catch rather than a wage so the time incurred in sorting the catch has no financial cost equivalent. On some boats, the crew could be employed elsewhere in processing the catch. Hence, spending additional time sorting the catch represents a loss of throughput through the processing process. However, as sorting the commercial component of the catch into separate species is still required before processing, the additional cost of separating out non-commercial species is difficult to quantify. To an extent, the non-commercial species may form the residual after the commercial species had been separated and removed.

On most boats the crew could be employed in preparing the net for the next shot if they were not required to sort the catch. Again, however, the value of these operations is difficult to separate out. In some fisheries, sorting takes place after the net (or whatever fishing gear is being used) has been re-deployed or the boat is returning to port after completing fishing. Hence, the crew may be otherwise unemployed if not sorting the fish. While removing the need to sort the fish would impart a benefit to the crew members in terms of greater 'leisure' time aboard the boat, the value of these benefits is difficult to quantify. The increased use of mechanical sorters further reduces the potential labour costs of discarding.

As an example of the costs of discarding non-commercial species, Alverson *et al* (1994) attempted to estimate the cost of 'wasted' effort associated with discarding pollock in the Bering Sea. They estimated that since 6.2 per cent of the pollock was discarded, 6.2 per cent of the effort was wasted as it was used to catch pollock later discarded. This amounted to approximately US$1.03 million in 1992, based on the variable costs of factory trawl operations. Such a measure is non-meaningful from an economic viewpoint as the marginal cost of capturing the discarded fish was zero (as it was a by-product of catching the retained fish). Unless the processing plant was operating at full capacity and the time spend sorting was greater than the time the net was towed, labour would not have been fully employed. Hence the opportunity cost of their time may have been negligible.

Costs associated with measuring/estimating the level of discards.

As noted earlier, a potentially major cost of discarding is the effect it can have on stock assessments if the level of discarding is unrecorded and the subsequent effects of inaccurate management advice on the fishery. To avoid this, a number of countries instigate programmes to estimate the levels of discarding. This is undertaken through the use of research vessels to estimate catch compositions, observer programmes and logbook programmes that have provision for discards.

Estimating the level of discards is a key research priority in the European Union. Between 1991 and 1994, the European Commission contributed 4.8 million ECUs to research projects aimed at estimating or reducing levels of discarding in European fisheries (European Commission 1996). The total cost of the research that was part funded by the European Union was estimated to be 8.9 million ECUs. This research expenditure excludes research that was fully funded by individual member states or other research funding agencies.

In a number of fisheries observers are employed to monitor the level of discards. Generally, observers are placed on a sample of vessels to record the catch composition and the amount and composition of the discarded catch. From this, total discards are extrapolated for the fishery as a whole. Observer costs in the US east coast fisheries are estimated to be in the order of US$120,000 a year, while in the Bering Sea and Gulf of Alaska groundfish and crab fisheries are in the range US$18,000 to US$60,000 (Alverson *et al* 1994).

Alverson *et al* (1994) estimated global costs associated with estimating or monitoring discards may be in the order of magnitude of US$4.5 billion. This is extrapolated from the estimated average management expenditure on monitoring or preventing discarding per unit of landed harvest weight in the USA. Given that each country approaches the problem of estimating discarding differently (and in many cases not at all), this estimate is likely to have wide confidence intervals. However, this notwithstanding, the likely global cost of discard monitoring is likely to be substantial.

2.4 Chapter summary

Bycatch is the incidental catch of a species or set of species that is caught while trying to target a particular species. Bycatch may consist of fish of the same species or fish of different species. Fish of the same species may be considered bycatch if they are of the wrong size, wrong part of the animal or the wrong sex. The definition of 'wrong' in such cases may be defined by either the market or imposed through regulation of the fishery. Bycatch of other species may be either marketable or non-marketable. In most cases, unmarketable bycatch is discarded, the key exception being where discarding is forbidden.

Bycatch occurs because fishing gear is not perfectly species or size selective and target species tend to live in habitats occupied by a wide range of other species. In some fisheries, the concept of target species is unclear, as fishers will attempt to catch a bundle of species rather than a single target species.

The total level of discarding has been estimated at between 18 and 40 million tonnes annually, with the most recent estimates suggesting it is nearer to the bottom end of the scale. This represents around one quarter of the total marine harvest. Shrimp fisheries account for about one third of the total global discards.

Discarding has a range of environmental and economic impacts. In most cases, discarded fish die. Large volumes of discards have resulted in reductions in the stocks of some species. Discarding of incidental catches of marine mammals, turtles and seabirds has caused considerable concern to environmental organisations. In other cases, discards have provided feed for other species. Seabird populations have increased in some fisheries largely as a result of the increased food supplied by the discards from commercial fishing boats.

A key problem with discarding from a fisheries management perspective is that the level of discards are often unknown. This creates problems for stock assessments and may lead to the provision of incorrect management advice. However, discarding is only one form of unrecorded catches, other forms including ghost fishing and mortality associated with escape from the fishing gear.

The economic impacts of discarding mainly fall into four categories. Discarding commercial target species results in a direct cost to the fishing industry in the form of foregone income. Discarding bycatch species can result in costs being imposed on other fisheries where the bycatch species may be the main target species. This has particularly been a problem with a number of shrimp fisheries where the discarded bycatch are juveniles of target species for other fisheries. The act of discarding itself may impose a cost on fishers as the catch has to be sorted and disposed of. Finally, the cost associated with trying to collect information on the level of discarding for the purposes of stock assessment may also be considerable in some fisheries.

3. Fisheries management and the economics of discarding

Fishing is primarily a commercial activity and all actions by the fisher are generally aimed at increasing their individual well being. Studies of fisher behaviour have suggested that fishers may attempt to maximise a number of goals, foremost of which is profit maximisation (Frost *et al* 1993, Hanna and Smith 1993, Hillis *et al* 1995, Robinson and Pascoe 1997). Given that fishing is an economic activity, fishers respond to economic incentives (Opaluch and Bockstael 1984).

The process of discarding is an economic activity associated with other fishing activities. As seen in the previous chapter, discarding is related to the level of bycatch, but is not synonymous with bycatch. In mixed fisheries, not all bycatch is discarded. In other fisheries, sub-groups of the target species are discarded. The decision to discard is a function of the relative costs and benefits of retaining and landing the fish or discarding it. For non-commercial species this decision is fairly straight forward as there are no benefits of landing the species. For commercial species, the decision to discard will depend on a number of factors and will vary from fishery to fishery.

A variety of fisheries management policies have been introduced in a number of world fisheries in order to overcome problems of overexploitation of the resource. These policies are generally introduced with the multiple objective of ensuring the sustainable use of the stock while improving the economic performance of the fishery. These policies generally aim at controlling either the level of the catch (output controls) or the level of fishing effort (input controls). In a number of fisheries, policies have been introduced specifically to address the problems of bycatch and discards.

Fisheries management affects the set of economic incentives facing fishers. Hence, the economic incentives to discard vary depending on the management plan in place. Fisheries management can take a number of forms. These range from no regulation at all (free and open access) to varying combinations of input and/or output controls. These management options influence the level of bycatch or discards by changing the incentives faced by fishers (and hence affecting their behaviour) or by changing the type of fishing technology used (Dewees and Ueber 1990).

In this chapter, the effects of the main types of input and output controls on the incentives to discarding will be examined. This will be done by examining the economic incentives to take and discard bycatch in an unmanaged fishery as well as under various management regimes. Policies aimed specifically at addressing the problem of discarding will not be covered in this chapter, but will be covered in detail in Chapter 5.

3.1 Bycatch and technical interactions in an unregulated fishery

Technical interactions between species are those imposed on the marine environment by the fishing practices of man. These may take a number of forms. In some cases, the species may be biologically independent, but occupy the same habitat, such that the species are caught simultaneously. In other cases, the species may be biological interdependent (as either predator/prey or competitors) and also caught simultaneously.

In many instances in a mixed species fishery, the fisher may actually be trying to target a particular species, but also catch other species unintentionally. As defined in the previous chapter, these other non-targeted species are generally termed bycatch. Bycatch can be either commercially valuable, in which case it is usually retained, or have no commercial value, in which case it is usually discarded.

In a mixed fishery, the level of fishing effort will depend on the combination of species caught and their relative prices. In an unregulated fishery, the existence of bycatch of low or non-commercial value species could conceivably lead to the depletion (and potential extinction) of those species. This can be explained through economic theory as well as being observed in several fisheries, as detailed in the previous chapter.

Following Clark (1985, 1990), consider two biologically independent species which are caught together. Species 1 is the main target of the fishing activity, but species 2 is caught as incidental bycatch. The level of catch of each species will depend on its catchability and stock size as well as the level of effort applied to the fishery. The change in stock of each species over time will be determined by the level of natural growth in the stock less the catch that is removed. This can be given by

$$\text{(3.1)} \qquad \frac{dB_1}{dt} = G_1(B_1) - q_1 E B_1$$

$$\text{(3.2)} \qquad \frac{dB_2}{dt} = G_2(B_2) - q_2 E B_2$$

where dB_1/dt and dB_2/dt are the rates of change in the biomass (B) of species 1 and species 2 over time, $G_1(B_1)$ and $G_2(B_2)$ are the natural growth in biomass of species 1 and species 2, q_1 and q_2 are the catchability coefficients[8] associated with each species and E is the level of effort. The same level of effort, E, is applied to both species. The catch of each species, represented by $q_i E B_i$, however, will be different, depending on the size of the biomass and the catchability coefficient of each species.

Assuming constant prices and cost per unit of effort, the annual level of profit (π) associated with the fishery is given by:

$$\text{(3.3)} \qquad \pi = (p_1 q_1 B_1 + p_2 q_2 B_2 - c)E$$

[8] The catchability coefficient is a coefficient that links the level of fishing effort to the proportion of the stock removed. The product of the catchability coefficient and the level of effort is generally termed the level of fishing mortality. This is expressed as a proportion of biomass.

where p_i is the price received per unit of catch of species i and c is the average cost of effort. In economic analyses, the measurement of costs is based on the opportunity cost of the inputs involved (e.g. labour and capital). The opportunity costs are the returns the input would receive if employed in the next best activity, and are often considered the normal return to the input. In the case of capital, the normal return is also considered the normal profit from the use of the capital input. Hence, the economic measure of profits in equation 3.3 represents returns above the normal returns, including the normal profit[9].

In the absence of fisheries regulation, the existence of above normal returns attracts additional effort to the fishery. Effort will increase until the above normal returns have been reduced to zero. That is, to the point where inputs are earning normal returns. Hence, the open access (bionomic[10]) equilibrium occurs when economic profits are equal to zero, giving the condition

$$(3.4) \qquad p_1 q_1 B_1 + p_2 q_2 B_2 = c$$

The system is in biological equilibrium when the catch of each species is equal to its growth. That is, $dB_1/dt = dB_2/dt = 0$. This gives

$$(3.5) \qquad E = \frac{G_1(B_1)}{q_1 B_1} = \frac{G_2(B_2)}{q_2 B_2}$$

The bionomic equilibrium exists when both equations 3.4 and 3.5 are met. Assuming a logistic growth function[11], equation 3.5 can be re-expressed as:

$$(3.6) \qquad \frac{r_1}{q_1}(1 - \frac{B_1}{k_1}) = \frac{r_2}{q_2}(1 - \frac{B_2}{k_2})$$

Equations 3.4 and 3.6 can be expressed in terms of the biomass of one species being given as a function of the other. For example, from equation 3.4,

$$(3.7) \qquad B_1 = \frac{c - p_2 q_2 B_2}{p_1 q_1}$$

and from equation 3.6

---

[9] For a fuller explanation see Anderson (1977) or Cunningham, Dunn and Whitmarsh (1985).

[10] The term 'bionomic' is often confused with the term 'bioeconomic'. The latter term refers to the general analysis of the system taking into account the biological and economic interactions. The former term relates particularly to the case of the open access equilibrium. That is, the equilibrium level of effort, catch and biomass in an unregulated fishery.

[11] A logistic growth function has growth increasing to a maximum level at half the carrying capacity of the stock, after which it decreases. Growth is zero when the stock is at the carrying capacity or at zero. Mathematically, the logistic growth function is expressed as $dB/dt=rB(1-B/k)$, where r is the instantaneous growth rate and k is the carrying capacity of the environment (that is, the maximum possible stock size the environment can sustain).

$$(3.8) \qquad B_1 = k_1[1 - \frac{r_2/q_2}{r_1/q_1}(1 - \frac{B_2}{k_2})]$$

Solving these two equations simultaneously gives

$$(3.9) \qquad B_1 = \frac{k_2(\frac{r_1 q_2}{r_2 q_1} - 1) + \frac{c}{p_2 q_2}}{\frac{p_1 q_1}{p_2 q_2} + \frac{k_2 r_1 q_2}{k_1 r_2 q_1}}$$

The biomass of species 2 at the bionomic equilibrium can be estimated in a similar way, giving

$$(3.10) \qquad B_2 = \frac{k_1(\frac{r_2 q_1}{r_1 q_2} - 1) + \frac{c}{p_1 q_1}}{\frac{p_2 q_2}{p_1 q_1} + \frac{k_1 r_2 q_1}{k_2 r_1 q_2}}$$

From this, it can be seen that it is possible for either (or both) stocks to be zero at the bionomic equilibrium. This would occur when the numerator of the equation was equal to zero. For example, B_1 would be equal to zero in equilibrium if

$$(3.11) \qquad k_2(\frac{r_1 q_2}{r_2 q_1} - 1) + \frac{c}{p_2 q_2} = 0 \quad \text{or} \quad k_2(1 - \frac{r_1 q_2}{r_2 q_1}) = \frac{c}{p_2 q_2}$$

While possible, it is unlikely that both stocks would be zero in equilibrium. A necessary and sufficient condition for the existence of the stock at the bionomic equilibrium is given by

$$(3.12) \; k_2(1 - \frac{r_1 q_2}{r_2 q_1}) < \frac{c}{p_2 q_2} \qquad \text{for } B_1 > 0$$

$$(3.13) \; k_1(1 - \frac{r_2 q_1}{r_1 q_2}) < \frac{c}{p_1 q_1} \qquad \text{for } B_2 > 0$$

From the above equations, it can be seen that the size of the stock of one species is dependent on the price of both itself and that of the other species. The lower the price of the second species, the greater the probability that the first species will not be driven to extinction. Intuitively, this is because the production decisions will become more dependent on the stock of the first species. If the stock falls too low, the fishery will generally become commercially unviable (unless the catchability is very high), and fishing will stop.

For example, from equation 3.12, if the price of species 2 was zero (that is, it has no commercial value), then the stock of species 1 will never be driven to extinction as the right hand side of the condition will be infinite. Whether or not the stock of species 2 will be driven to extinction will depend on the price of species 1, and the relative growth and catchability of both species. The higher the price of species 1, the greater the chance that the species 2 will be driven to extinction as the right hand side decreases as the price increases.

The effect of the level of effort that generates the combined maximum economic yield on the stock of each species will depend on the growth rate of the two species and the catch effort relationship. For example if the bycatch species has no commercial value and has a relatively low growth rate, it is conceivable that the bycatch species could be driven to extinction in the process of harvesting the commercial target species.

This is illustrated in the left hand side of Figure 3.1, where it can be seen that the level of effort at the open access equilibrium is greater than the maximum level of effort the bycatch species can sustain. Even if the bycatch species had a commercial value, the overall level of effort in the fishery at the open access equilibrium would have resulted in its extinction.

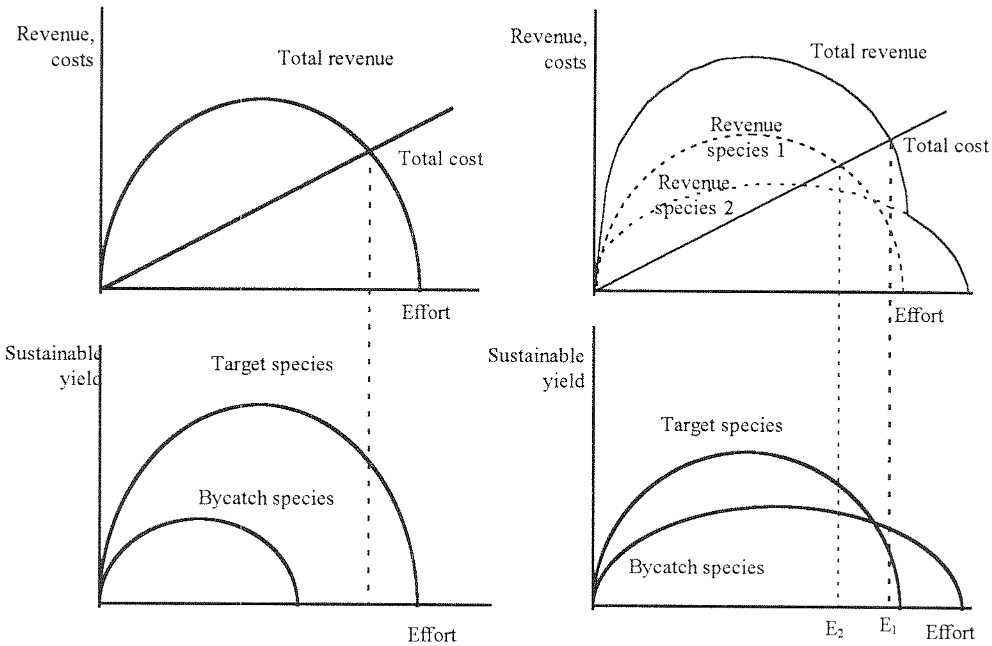


Figure 3.1 Open access equilibrium in a two species joint catch fishery

In contrast, if both species had similar growth and carrying capacity (as in the right hand side of Figure 3.1), then a sustainable yield would exist for both species at the open access equilibrium. If both species had commercial value, then the open access equilibrium would occur where the total cost curve intersects the combined (cumulative) total revenue curve for the fishery as a whole, resulting in effort level E_1. In contrast, if the bycatch species had no commercial value, then the open access equilibrium would occur at the lower level E_2. That is, where the total cost curve intersected the revenue curve for species 1 only. From this, the existence of commercial bycatch species in multispecies fisheries may result in a higher level of exploitation of the target species than in the case of a single species fishery.

From a stock conservation perspective, the two species illustrated in the right hand side of Figure 3.1 would both be better off if the bycatch species was discarded rather than landed. In such a case the level of effort in the fishery would not expand beyond E_2 in the long run. If the bycatch species has a commercial value, then this results in the total level of effort being expended in the fishery being greater (E_1). The sustainable yield of both species is higher at the lower effort level E_2 than at E_1. While not depicted in Figure 3.1, the higher sustainable yield would be associated with a higher biomass for both species.

3.2 Discarding of commercial species in an unregulated multispecies fishery

The above discussion focused on the effects of technical interactions in the fishery and the resultant levels of catch and biomass of the target and bycatch species. The level of bycatch and discarding in an unregulated fishery will vary fishery by fishery. If the target species occurs in single species aggregations, then the level of incidental catch will be low. The further the stock structures differ from this ideal, the greater will be the level of bycatch and discarding (Andrews 1990a).

A general assumption is often made that while all non-commercial species would be discarded under open access, there is no incentive to discard commercial bycatch species. This, however, is not necessarily the case.

Discards of commercial species in an unregulated fishery can occur for two reasons. First, the price received for the fish does not compensate the skipper for the costs involved in its handling and sending to market; second, the boat faces a storage capacity constraint and the skipper is better off utilising the available storage capacity for higher valued species. These forms of discarding are referred to as highgrading. That is, the value of the catch is maximised by landing only the higher valued components.

3.2.1 Price related highgrading

The first form of highgrading occurs largely in a fishery with different grades of fish receiving different prices. For discarding to occur, the different grades need to be detectable by fishers so need to be defined in terms of some physical characteristic of the fish (Arnason 1994). For example, the grades may be defined in terms of either sex, size, skin damage, colour or some other obvious feature of the fish.

The incentives to land or discard the fish of each grade will depend on the price received, the costs of landing the fish and the costs associated with discarding the fish. Arnason (1994, 1995) developed a discard rule describing the conditions under which discarding is an economically rational activity. Following Arnason (1994, 1995), consider a fishery consisting of $i = 1, \ldots, I$ grades of fish. These each attract a separate price on the market, p_i. The total catch (C) is the sum of the catch of the individual grades, such that

$$(3.14) \qquad C = \sum_i C_i(e,x,i)$$

where $C_i(e,x)$ is the catch of grade i, a function of the level of effort, e, the stock biomass, x, and the grade composition of the catch, i. The catch of each grade may be either landed or discarded, where the quantity landed is given by l_i and the quantity discarded is given by d_i. The relationship between landings and discarding can be expressed by

$$(3.15) \qquad l_i = C_i(e,x,i) - d_i$$

Both landing and discarding impose a cost on the fishery. These can be defined by non-decreasing, convex cost functions $CL_i(l_i)$ and $CD_i(d_i)$, where $CL_i(l_i)$ is the cost of landing grade i, a function of the quantity of landing of grade i; and $CD_i(d_i)$ is the cost of discarding grade i, a function of the quantity of discards of grade i. The costs of landing the fish include activities such as preliminary fish processing (e.g. the labour involved in gutting and gilling), storing (e.g. ice costs) and handling (e.g. crate costs) as well as actual costs involved in landing the fish (e.g. landing levies and transport costs to the market). The costs of discarding are expected to be relatively low for low quantities of discards as discarding is relatively easy, but would increase with the quantity of discards as a greater proportion of the crew time would be involved in the discarding process[12].

The profit of the fishing operation is given by

$$(3.17) \qquad \pi(e,\boldsymbol{d},x,\boldsymbol{p}) = \sum_i p_i l_i - CE(e) - \sum_i CL_i(l_i) - \sum_i CD_i(d_i)$$

where $CE(e)$ is the cost of effort, taken as a function of the level of effort, e. From this, total profit is a function of the level of effort, e, the set of discards, $\boldsymbol{d}$, the stock size, x, and the set of prices, $\boldsymbol{p}$. Maximising profits with respect to the level of discards, d_i, results in the necessary condition relating to the optimal level of discards. From this, discarding fish of grade i is economically rational if:

$$(3.18) \qquad p_i + CD_i(0) < CL_i(C_i(e,x,i) - 0) \text{ for all } i$$

The left hand side of the inequality represents the marginal cost of discarding. This is comprised of the forgone price received on the market (the opportunity cost of the discarded fish) and the cost of discarding the fish itself, evaluated at the zero discard level. The right hand side of the inequality is the marginal benefit of discarding. This is the landing costs not incurred if the fish are discarded. These are also evaluated at the zero discarding level.

---

[12] Arnason (1994) also points out that if discarding is illegal or socially frowned upon, the cost of discarding may be substantially higher.

From this rule, Arnason (1994) develops a discarding function, given by

$$(3.19) \quad \Gamma_i = CL_i(C_i(e,x,i) - 0) - p_i - CD_i(0)$$

If the value of the discarding function for a particular grade is positive, the catch of that grade will be discarded. Conversely, if the value of the discarding function is negative, the catch will be retained. The value of Γ_i is hence a measure of the propensity to discard or retain the catch.

The discarding function may take a number of shapes. For example, in the left hand side of Figure 3.2, grades to the left of i^* would be discarded while fish in grades above i^* would be retained. Hence, i^* can be considered to be the minimum economic size of the fish.

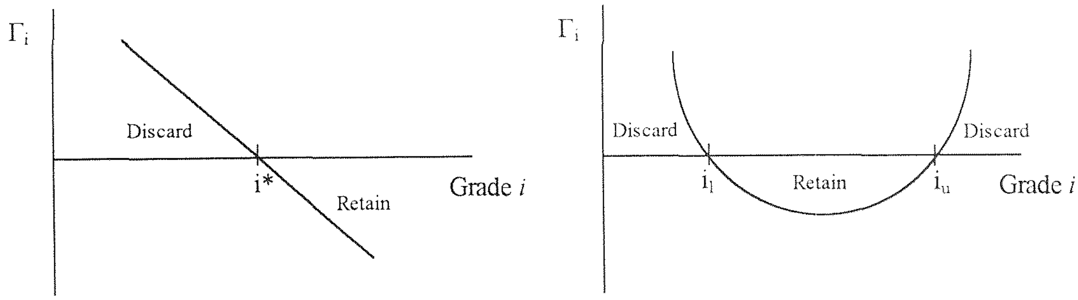


Figure 3.2 Examples of discarding functions
source: Arnason (1994, 1995)

In the right hand side of Figure 3.2, catch of size grades below and above grades i_l and i_u respectively would be discarded while the middle grades would be retained. This latter situation might occur for fish that are primarily consumed in the restaurant trade, where 'plate sized' fish attract a price premium. Fish too small or too large for this market would receive a substantially lower price.

In most cases, different size classes are the main cause of price related highgrading, although damaged fish would also be discarded for the same reasons. Given that fishers are able to modify their gear to target particular size classes, the incentives to high grade need to be compared with the incentive to modify the gear in order to avoid the capture of the smaller fish.

Arnason (1995) extended the above analysis to incorporate varying size selective fishing gear. In this case, the harvesting function can be represented by

$$(3.20) \quad y_i = C_i(e,x,i).(1 - a_i)$$

where y_i is the harvesting function of grade i, $C_i(e,x,i)$ is the 'unselective' harvesting function and a_i is the selectivity factor ($0<a_i<1$). When a_i is equal to 1, none of the size class i are caught. Conversely, when $a_i=0$, all of the size class i are harvested by the gear.

Associated with the gear is a selectivity cost function, $CS_i(a_i)$, which is a function of the selectivity parameter a_i. The profit function can be redefined as

$$(3.21)\qquad \begin{aligned}\pi(e,d,x,p) = \sum_i p_i\left[C_i(e,x,i).(1-a_i)-d_i\right] - CE(e) - \sum_i CL_i(l_i) \\ -\sum_i CD_i(d_i) - \sum_i CS_i(a_i)\end{aligned}$$

Differentiating this profit function with respect to effort, discards and selectivity results in the necessary first order conditions for profit maximisation by the fisher:

$$(3.22)\qquad \sum_i p_i\left[C_i'(e,x,i).(1-a_i)\right] - \sum_i CL_i'(l_i(e)) = CE'(e)$$

$$(3.23)\qquad -\left[p_i - CL_i'(l_i)\right] \le CD_i'(d_i)$$

$$(3.24)\qquad -\left[p_i C_i(e,x,i)\right] - CL_i'(l_i) \le CS_i'(a_i)$$

From the first condition, a profit maximising producer will continue to apply effort to the fishery until the marginal benefit of fishing (the revenue from catching the marginal fish less the cost of landing the marginal fish) was equal to the marginal cost of the additional unit of effort evaluated at the total effort level, e, (i.e. $CE'(e)$). The second condition is a restatement of the previous condition in equation (3.18), where the net price received from landing the fish must be both negative and less than the cost of discarding before discarding is an optimal option[13]. The final condition indicates that in order to employ more selective gear rather than discard, the net benefits received from landing the size class i (this is the price times the quantity caught, assuming no discards) must be both negative and less than the marginal cost associated with achieving that level of selectivity.

From these conditions, Arnason (1995) demonstrated that if the marginal cost of discarding (evaluated at the level of discarding) is less than marginal cost of selectivity (evaluated at zero selectivity) (i.e. $CD_i'(d_i) < CS_i'(0)$), then the profit maximising fisher will only discard and not employ selective gear. Conversely, if the marginal cost of discarding evaluated at zero discards is higher than the marginal cost of selectivity (i.e. $CS_i'(a_i) < CD_i(0)$), then the profit maximising fisher will only employ selective gear and avoid unwanted size classes of fish, hence removing the need to discard. Finally, both selectivity and discarding may occur simultaneously. The optimal combination of use of selective gear and discarding is given by the condition

$$(3.25)\qquad CS_i'(a_i) = CD_i'(d_i)$$

Following Arnason (1995), this relationship can be demonstrated graphically. In Figure 3.3, the marginal cost of discarding and selectivity intersect the benefits of not landing (the negative of the net price) at d and a respectively. From this, the optimal

---

[13] In absolute value terms, the net cost of landing the fish must be greater than the cost of discarding before discarding is economically rational.

selectivity will be a, and the proportion discarded (after selectivity) will be d. Hence, the quantity of discards of grade i would be $C_i(e,x,i).(1-a).d$ (Arnason 1995).

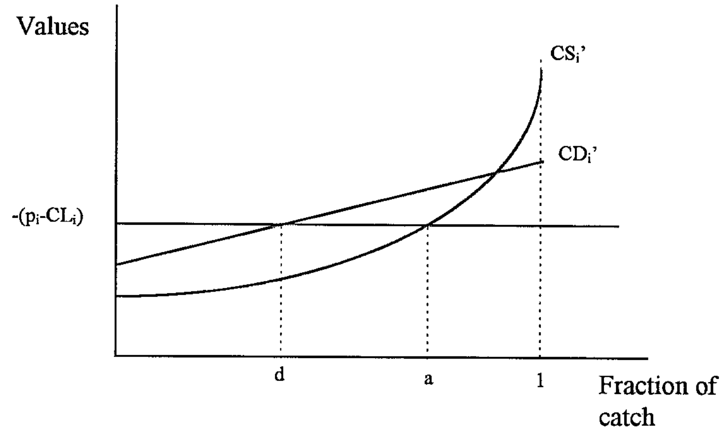


Figure 3.3 Optimal discarding and selectivity
source: Arnason (1995)

In reality, these conditions would vary trip by trip and the size (or other grade) composition will vary shot by shot. Catch compositions can vary according to season, location, type of gear and the way the gear is employed (Anderson 1994). Even if fishers were able to estimate accurately the catch composition, it is most likely that the cost of changing the gear for each trip would be prohibitive (not alone the expense of having sufficient types of gear to met the optimal requirements for each trip. Hence, it is unlikely that fishers could ever operate at the optimal mix of selectivity and discarding. However, it is likely that fishers would have some pre-defined expectations about the average catch composition and may incorporate selective gear on that basis.

The above analysis does demonstrate, however, that it is perfectly rational behaviour for fishers to discard some grades of fish in the absence of regulation. While it is possible to employ selective gear in some cases so that the unwanted catch is avoided, this may not necessarily be the most rational behaviour from the perspective of the individual fisher.

3.2.2 Capacity related highgrading

Highgrading can also occur when there is a limit on the amount of fish that can be stored on board or limitations on the amount of ice that can be produced to keep fish fresh (Cunningham 1993). In such cases, it may be optimal to discard certain types or grades of fish even if the conditions suggested by Arnason (1994, 1995) above do not hold (i.e. that the net price of the fish must be negative and that it must be less than the cost of discarding).

For each boat with a constraint on the quantity of fish it can return to shore, the critical decisions faced by the skipper are how long to fish and what types of fish to keep (Anderson 1994). Anderson (1994) examined the problem using a constrained optimisation approach to estimate the optimal decision rule for discarding. Following Anderson (1994) (but maintaining the notation used above), the trip profit function may be given by

$$(3.26) \qquad \pi = \sum_i p_i\left[C_i(e,x,i) - d_i\right] - CE(e) - \sum_i CD_i(d_i)$$

In this case, grade i can represent a particular size grade, or may represent a bycatch species that has a different value to the target species. The profit function in this case is constrained by two factors. First, the amount of landings must be less than or equal to the volume that can be stored in the hold; and second, the amount of discards must be less than the total quantity caught. These can be expressed respectively as

$$(3.27) \qquad \sum_i \left(C_i(e,x,i) - d_i\right) \leq B$$

$$(3.28) \qquad d_i \leq C_i(e,x,i)$$

where B is the hold volume expressed in terms of the amount of fish that can be stored.

These constraints can be incorporated into the maximisation process through the Lagrangian[14], given by

$$(3.29) \qquad \begin{aligned} L = {} & \sum_i p_i\left[C_i(e,x,i) - d_i\right] - CE(e) - \sum_i CD_i(d_i) \\ & + \lambda\left[B - \left(\sum_i C_i(e,x,i) - d_i\right)\right] + \sum_i \gamma_i\left(C_i(e,x,i) - d_i\right) \end{aligned}$$

where λ and γ_i are Lagrangian multipliers associated with the constraint. If the constraint is non-binding, these take the value of zero. However, if the constraint is binding, they take on a non-zero value representing the shadow value of the constraint. This is the value of an additional unit of the constraint. For example, λ in this case is the value of one additional unit of hold capacity while γ_i is the value of discarding an additional unit of fish.

The necessary conditions for profit maximisation are derived by differentiating the Lagrangian with respect to effort and discards of each grade i. These are given by[15]

$$(3.30) \qquad \frac{\partial L}{\partial e} = \sum_i p_i C_i'(e,x,i) - CE'(e) - \lambda \sum_i C_i'(e,x,i) + \sum_i \gamma_i C_i'(e,x,i) \leq 0$$

---

[14] The Lagrange function (or Lagrangian) is used in problems involving constrained optimisation. The function consists of the component to be optimised (i.e. the profit function) as well as the constraints. The constraints are expressed as equalities rather than inequalities, and are multiplied by a new variable known as the Lagrangian multiplier.

[15] Two further necessary conditions not presented are that $e(\partial L/\partial e) = 0$ and $d(\partial L/\partial d) = 0$. Hence, either the variable or the derivative with respect to that variable must take on the value of zero. As the value of effort and discarding can be assumed to be non-zero, the derivatives must equal zero. This fact will be utilised in the following analysis.

(3.31) $\frac{\partial L}{\partial d_i} = -p_i - CD'(d_i) + \lambda - \gamma_i \leq 0$ for each i

With a large number of species or grades, solving this set of conditions is difficult. For the purposes of demonstration, assume that there are only two species that are caught in constant proportion. Also, if we assume that the catch per unit of effort is constant and the cost per unit of discarding is constant and the same for both species, the two necessary conditions can be expressed as

(3.32) $\frac{\partial L}{\partial e} = p_1 \alpha y + p_2(1-\alpha)y - CE'(e) - \lambda y + \gamma_1 a y + \gamma_2(1-a)y \leq 0$

(3.33) $\frac{\partial L}{\partial d_i} = -p_i - D + \lambda - \gamma_i \leq 0$ for each i

where y is the average catch per unit of effort, α is the proportion of catch that is comprised of species (or grade) i and D is the marginal cost of discarding a unit of either species.

In practice, it will be optimal to highgrade only one species (or size class). If the price of one species is less than that of the other, there is no benefit in discarding the more valuable species in order to land the less valuable species. Hence, the shadow price associated with discarding for one species will be zero. For the purposes of example, assume that the second species (or size grade) has a higher price than the first and is not discarded, such than $\gamma_2=0$.

The amount of catch required to fill the hold with the higher valued species is equivalent to $B/(1-\alpha)$[16]. That is, the capacity of the hold divided by the proportion of the catch that consists of the higher valued species. If total catch is less than B, then the shadow value associated with the hold is zero (i.e. $\lambda = 0$). From equation 3.33, the shadow value of discarding under such conditions is given by

(3.34) $\gamma_i = -p_i - D$

That is, the shadow price of discarding is the forgone price that could be received and the cost of discarding itself. As this is negative, discarding an additional unit of fish will decrease profits. Hence, discarding under such conditions would not be rational behaviour. This condition is fairly intuitive and did not need such complex calculus to determine. However, it does indicate that the model provides intuitive answers under such conditions, validating the technique.

If the capacity constraint was binding, however, then the shadow price associated with the hold constraint would be positive. Equation 3.32 can be simplified by dividing

[16] This is also the profit maximising level of catch given the hold constraint B (Anderson 1994).

through by the catch rate, y, and taking into account the zero shadow price of the second species, giving

$$(3.35) \qquad p_1\alpha + p_2(1-\alpha) - \frac{CE'(e)}{y} - \lambda + \gamma_1\alpha \le 0$$

These equations can be solved simultaneously to derive the shadow prices associated with a unit of storage space in the hold and discards of each species. Solving equation 3.35 for λ gives

$$(3.36) \qquad \lambda = p_1\alpha + p_2(1-\alpha) - \frac{CE'(e)}{y} + \gamma_1\alpha$$

Substituting this back into equation 3.33 and solving for the lower valued species (the species that may be discarded, assumed to be species 1) gives

$$(3.37) \qquad \gamma_1 = p_2 - p_1 - \frac{1}{(1-\alpha)}\left[\frac{CE'(e)}{y} + D\right]$$

The shadow value of discarding the first species is consequently related to the net benefit of landing only the higher valued species. This is largely a function of the price difference that can be received by landing only the higher valued species (i.e. p_2-p_1). However, this benefit is reduced by the additional costs incurred in replacing the discarded species 1 by fishing longer to catch more of species 2 and the costs associated with discarding themselves. The costs of capturing the additional fish and the costs associated with discarding vary inversely with the proportion of the catch that is comprised of the target species, $(1-\alpha)$.

From this, it can be seen that discarding lower valued species may be rational under unregulated fisheries where the boats are subject to hold capacity constraints. These constraints will vary from trip to trip, depending on the various catch rates and catch compositions. For some trips, it may not be rational to discard at all if the hold capacity is not reached. However, some fishers may discard part of their catch early during the trip in anticipation of filling the hold. In other cases, fishers may choose to store lower valued fish and discard these only when the hold capacity is met. For example, Japanese longliners operating in the Atlantic have been observed to discard Albacore and other lower valued species after processing and storage in the freezer if the hold space is subsequently required by more valuable species such as yellowfin or blue fin tuna (Crestin 1997).

As with discarding due to grade differences where fishers could opt to alter the selectivity of their gear, fishers also may be able to alter the size of their holds in order to reduce the amount of discarding. The value of increasing the hold is equivalent to the shadow price associated with the hold constraint, λ. This can be estimated by substituting equation 3.37 back into equation 3.36, giving:

$$(3.38) \qquad \lambda = p_2 - \frac{1}{(1-\alpha)}\left[\frac{CE'(e)}{y} - \alpha D\right]$$

From this, the value of an additional unit of hold capacity is equivalent to the price of the additional unit of fish that could be landed (p_2) less the cost of the capture of the target species and the cost associated with discarding the lower valued species.

The cost of increasing the hold size is a capital cost. Once increased, larger catches can be taken in every subsequent trip. Hence the cost of increasing the hold needs to be compared with the flow of future benefits (λ) discounted over the life of the hold. If the net present value is positive, taking into account the trips where the hold capacity will not be reached, then it is worth investing in a larger hold. This is not likely to have a substantial effect on the level of discarding as it will lead to an increased catch (as the new profit maximising catch level will be based on the greater hold capacity) and associated levels of discarding. However, there will also be trips where discarding would have occurred given the smaller hold but where the larger hold can now accommodate both the target and bycatch species. Overall, the effect of increasing the hold capacity on the total level of discards may be positive or negative.

3.3 Input controls

Input controls can take a number of forms. These include limited entry, minimum landing sizes of the fish, minimum mesh sizes, area or seasonal closures, days at sea restrictions and restrictions on other physical inputs (e.g. boat size, engine power, etc.). Often, one or more controls are imposed on the fishery simultaneously. These controls can affect the incentives to discard in different ways.

3.3.1 Limited entry

Licence limitations can theoretically reduce the level of effort in a fishery, and hence affect the level of catch, bycatch and discarding (Lowman 1990). The effect, however, depends on the state of the stocks in the open access equilibrium and the degree to which effort is reduced.

In the short term, a reduction in effort will result in a reduction in overall catch. Consequently, it could be expected that the level of discarding would decrease accordingly. However, limited entry management systems are often imposed after a fishery has become overcapitalised and effort levels are excessive (Andrews 1990b, Lowman 1990). In such cases, the effect of the policy is to prevent new entrants rather than to decrease the existing level of effort. Hence there may not be a short run reduction in catch and a corresponding decrease in discarding.

Where effort is reduced, the long term effect may be either to increase or decrease discarding. In the long term, stock sizes can change in response to the change in catch levels. This will affect the level of sustainable catch of both the target and bycatch species.

For example, in the left hand side of Figure 3.4, reducing the level of effort from E_1 to E_2 has no appreciable effect on the stock of the bycatch species (which is assumed to have no commercial value for the purpose of the illustration). This is because the bycatch species is driven to extinction under both levels of effort. Hence, in the long run, discarding of the bycatch species would be zero as none would be caught.

Reducing the level of effort to that approximating the profit maximising level, E_3 (estimated as the level of effort where the vertical difference between the total revenue curve and the total cost curve is greatest), the bycatch species would not be driven to extinction. However, long run discarding of the species would be expected at the level B_3.

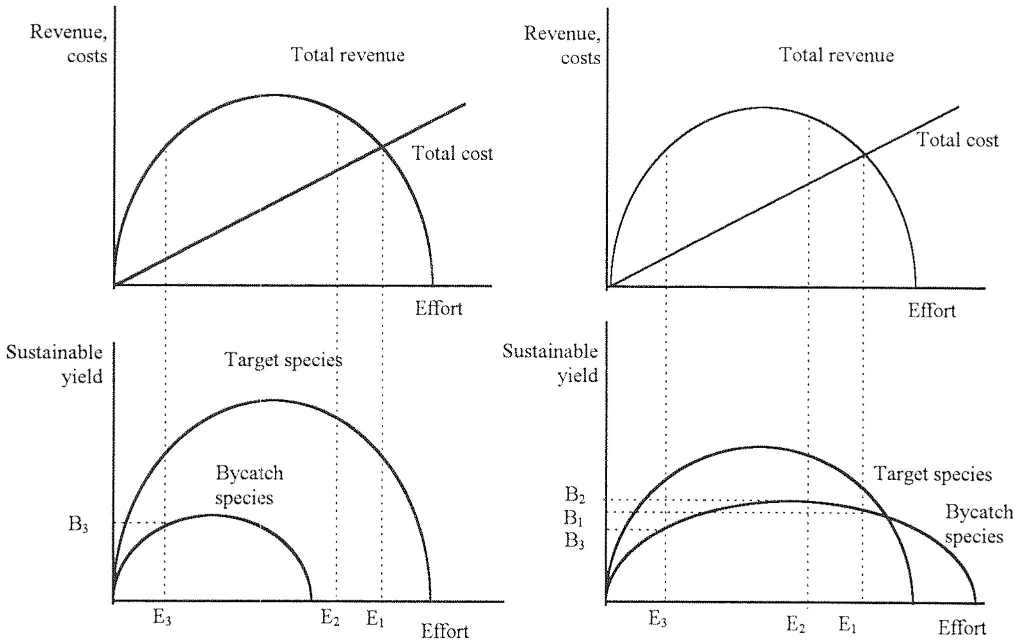


Figure 3.4 Limited entry in a two species joint catch fishery

In the right hand side of Figure 3.4, reducing effort from E_1 to E_2 results in a higher sustainable catch of the bycatch species (B_2). If this species has no commercial values, the reduction in effort would result in increased long term levels of discards (i.e. from B_1 to B_2). In contrast, reducing the effort level to around the profit maximising effort (E_3) may result in a reduction in the long run level of bycatch and discarding to B_3.

In both cases described above, the increased levels of discarding are associated with increased stock sizes. Hence it is difficult to argue that the increase in discarding is, from a biological perspective, a bad thing. This is particularly the case in the left hand diagram where the absence of discarding under open access is a reflection of the extinction of the species, while discarding at the profit maximising level of effort is indicative of a healthy, sustainable stock.

The introduction of limited entry schemes can also result in increased fishery profit and higher sustainable catches of the target species. For example, in both sides of Figure

3.4 effort level E_2 results in a greater level of fishery profit than E_1, and also a higher sustainable yield of the target species. An effort level of E_3 results in a much greater level of fishery profit than E_1, with about the same sustainable yield of the target species. Hence, the possible effects of discarding need to be balanced with the possible benefits of effort reduction associated with limited entry.

The longevity of these benefits, however, depend on the ability of managers to maintain effort at the lower level. In most cases where limited entry has been applied, effort has continued to expand through some other factors. These include substitution of other inputs (such as engine power or boats size) or days fished. Studies of input substitution have generally determined that fishers are able to overcome most input controls to a degree, particularly licence limitations (see for example Squires 1977, Campbell and Lindner 1990, Campbell 1991, Robinson and Pascoe 1996). Hence, the benefits of effort reduction may be more short term in nature rather than long term.

The imposition of limits on licences does not remove the incentives to discard commercial species that were already in existence under open access. If the commercial species is differentiated by grade (either size, sex or other physical feature), then their may still be incentives to discard a portion of the catch. The condition for this to occur was established in equations 3.18 and 3.23, where there must exist a net cost in landing the fish, and this net cost must be greater than the cost of discarding. Similarly, where the boats are constrained by the size of the hold, highgrading of catch may also result in discarding of commercial species under limited entry management.

As noted in the previous chapter, discarding of small commercial species has been observed in the Australian south east fishery while under both open access and limited entry management. In particular, large quantities of small redfish were being discarded as the price received was too low to warrant marketing (Baulch and Pascoe 1992). Discarding of commercial species has also be recorded in the Australian northern prawn fishery and the North Carolina and south east shrimp fishery (US). In both fisheries, capacity constraints were main factors affecting the decision to discard. Only high valued species were retained as these could compete for hold space with the valuable shrimp catches (Murray, Bahen and Rulifson 1992, Pender, Willing and Cann 1992).

Andrews (1990b) and Smith (1990) suggest that limited entry provides an opportunity for fishers to work co-operatively and hence deal with problems associated with bycatch. This would involve agreeing to adopt voluntarily alternative types of more selective gear. As in the case of the unregulated fishery, it would be expected that fishers would adopt more selective gear anyway if the cost of discarding was greater than the cost of the gear. The cost of discarding may include non-market costs such as those arising from social unacceptance of the practice (Arnason 1994) which might increase if fishers grouped together.

From the above discussion, limited entry does not address the bycatch and discarding 'problem' directly and may provide few if any benefits in terms of bycatch reduction (Lowman 1990, Pooley 1990). In some cases, as described above, the introduction of limited entry may increase the level of discarding. However, from a conservation perspective, such an increase in discards may be more desirable than an overexploited stock with correspondingly lower levels of discards.

3.3.2 Minimum landing sizes and minimum mesh sizes

Minimum landing sizes are often employed in fisheries to overcome two problems: growth overfishing and recruitment overfishing (Hill 1992). Minimum landing size restrictions are generally complemented by minimum mesh size restrictions in net based fisheries (i.e. trawl, gillnet, trammel net etc.).

Growth overfishing occurs when the fish are taken at a smaller size, hence the total output of the fishery is less than it could otherwise be. Biologists generally consider growth overfishing to produce a lower biomass than could otherwise be harvested on a sustainable basis from the fishery, based on the yield per recruit. Provided mortality rates do not exceed the growth rate, then the total yield of the fish can be increased by harvesting the stock at a later age than might occur in the absence of regulation (Beverton and Holt 1957). Die *et al* (1988) expanded this concept to consider the utility per recruit. That is, the average value of the fish at various ages, taking into account mortality rates, growth rates, number of new recruits produced and changes in value (e.g. price for market fish or non-market values for recreational fish). Theoretically, the legal minimum landing size can be set in order to maximise the utility or yield per recruit.

Recruitment overfishing occurs when the spawning stock is reduced through overfishing, resulting in lower levels of recruitment than might otherwise be possible. Imposing a minimum size limit theoretically protects the immature fish and enables a greater number to survive to join the spawning stock. The minimum size does not necessarily have to be the size at which the fish first spawn in order to increase the chance of survival to spawning size, although the closer the minimum size is to this the more effective the regulation becomes (Hill 1990).

Under a minimum size limit, all undersized fish would be discarded as the cost of landing the fish would include a penalty prescribed by the regulation. Hence the net price (assuming that the fish could attract a price on the market) would be expected to be negative. As indicated in the analysis of the unregulated fishery, fishers would only voluntarily adopt selective gear to avoid capture of undersized fish if the marginal cost of adopting the gear was less than the marginal cost associated with discarding the catch. Otherwise, as in an unregulated fishery the fisher would be better off to discard the undersized fish.

The overall effect on the level of discarding also depends on how the minimum legal size compares with the size of the fish that would be discarded in the absence of the regulation. If the minimum legal size is less than the economic minimum size (as in the left hand side of Figure 3.5), then the introduction of the minimum size is not likely to have any effect on the level of discarding. However, if the minimum legal size is greater than the minimum economic size (as in the right hand side of Figure 3.5), then the level of discarding is likely to increase as a result of the introduction of the size limit.

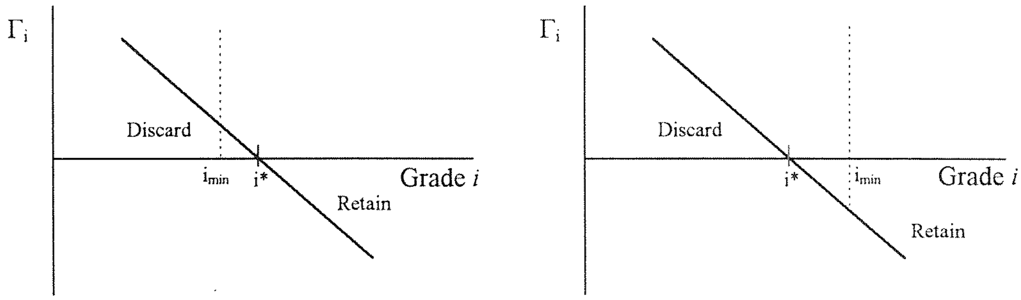


Figure 3.5 Effects of minimum legal size on discards

Discarding costs in most fisheries are not likely to be significant, so the imposition of a minimum landing size would, in most cases, result in an increase in discarding. This has been observed in most fisheries where minimum legal landings sizes have been imposed. As survival of discards are low for most species, the potential value of imposing minimum landing size restrictions in most fisheries is undermined by this problem (Hill 1990).

As noted above, to overcome this problem minimum legal size restrictions are often complemented by minimum mesh size restrictions. In theory, minimum mesh sizes allow the smaller fish to escape, with a proportion of these being re-caught at a later date at a more valuable size (Ueber 1990). In practice, undersized fish are often still caught and discarded. Further details on the use of gear selectivity as a bycatch management tool are given in Chapter 5.

3.3.3 Area and seasonal closures

Area and seasonal closures have been implemented in a number of fisheries in an attempt to prevent fishers operating where or when catches of unwanted fish are likely to be high. By avoiding capture of these fish, the level of discarding (and resultant mortality) is likely to be lower than might otherwise occur. As these are used primarily as bycatch management tools, the effectiveness of these measures will be reviewed in Chapter 5.

3.3.4 Restrictions on days at sea and other inputs

The objective of days at sea restrictions and restrictions on other inputs is to reduce (or constrain) the level of effort in the fishery. These are often imposed to complement limited entry schemes and prevent increases in effort by the boats entitled to fish. As a result, their effect on bycatch and discarding is analogous to that of the limited entry management outlined above. That is, they may result in an initial decrease in discarding, but (provided effort can be effectively maintained at the lower level), may result in a higher level of discards in the long run, depending on the state of the stock and the overall reduction in the level of effort.

Vestergaard (1996) extended the analysis of Clark (1985) and Anderson (1994) described earlier by incorporating the effects of a limited season (equivalent to a days-at-sea restriction). This was to estimate the effects of such restrictions on the levels of discards.

Following Vestergaard (1996), the profits to an individual fisher that can be obtained from fishing for the season as a whole can be given by

$$(3.39) \qquad \pi = N\left\{\sum_i \left[p_i(a_i yE - D_i) - cl_i(a_i yE - D_i) - c_d D_i\right] - CE(E)\right\}$$

where N is the number of trips, E is the number of days fished each trip (i.e. a measure of fishing effort) assumed constant for each trip, D_i is the total discards each trip of size class i, a_i is the proportion of the catch of size class i, y is the total catch per unit of effort (i.e. the catch of all size classes), p_i is the price received for size class i, c_d is the cost of discarding one unit of catch and $CE(E)$ is the total cost of effort each trip (a function of the level of effort).

The amount of profits that the individual fisher can earn is limited by a number of constraints. These include the number of days that can be fished given the restriction on days at sea and the hold capacity of the vessel. These constraints can be represented as

$$(3.40) \qquad N(E + E_0) \leq T, \text{ and}$$

$$(3.41) \qquad \sum_i a_i yE - D_i \leq B$$

where T is the total number of days the fisher is permitted to fish, E_0 is the steaming time (i.e. non fishing time) expended by moving to and from the fishing grounds and B is the capacity of the hold, representing the maximum quantity of fish that can be landed in any one trip. A further constraint is added to the model for completeness, namely that the level of discards cannot exceed the quantity caught, given by:

$$(3.42) \qquad a_i yE - D_i \geq 0$$

This is similar to the analysis of effects of hold constraints on the decision to discard in an unregulated fishery presented earlier, with the exception that the profit function is now an annual function instead of a trip function, and that the number of trips are limited by management. As in the previous analysis, the Lagrangian function can be represented by

$$(3.43)\quad \begin{aligned} L = {} & N\left\{\sum_i\left[p_i(a_iyE - D_i) - cl_i(a_iyE - D_i) - c_dD_i\right] - CE(E)\right\} \\ & +\lambda_1\left(T - N(E+E_0)\right) + \sum_i \lambda_{2,i}\left(a_iyE - D_i\right) + \lambda_3\left[B - \sum_i\left(a_iyE - D_i\right)\right] \end{aligned}$$

where λ_1 is the shadow price of an additional day that can be fished, $\lambda_{2,i}$ is the shadow price associated with the discarding constraint for each size class i and λ_3 is the shadow price of an additional unit of hold capacity. Differentiating this function with respect to the number of trips, the length of each trip and the level of discarding results in the necessary conditions for profit maximisation:

$$(3.44)\quad \frac{\partial L}{\partial N} = \sum_i\left[(p_i - cl_i)(a_iyE - D_i) - c_dD_i\right] - CE(E) - \lambda_1(E+E_0) \le 0$$

$$(3.45)\quad \frac{\partial L}{\partial E} = N\sum_i\left[(p_i - cl_i)a_iy - CE'(E)\right] - \lambda_1N + \sum_i\lambda_{2,i}a_iy - \lambda_3\sum_i a_iy \le 0$$

$$(3.46)\quad \frac{\partial L}{\partial D_i} = -N(p_i - cl_i + c_d) - \lambda_{2,i} + \lambda_3 \le 0 \text{ for each size class i}$$

Associated with these necessary conditions are the further first order conditions that $N(\partial L/\partial N)=0$; $E(\partial L/\partial E)=0$ and $D_i(\partial L/\partial D_i) = 0$[17]. Hence, if N, E, and D are greater than zero (as would be expected), the three inequalities in equations 3.44 to 3.46 can be replaced with equal signs.

The shadow value of the days-at-sea restriction can be estimated from equation 3.44, given as

$$(3.47)\quad \lambda_1 = \frac{\sum_i\left[(p_i - cl_i)(a_iyE - D_i) - c_dD_i\right] - CE(E)}{E+E_0}$$

The right hand side of equation 3.47 is the average profit per day at sea (APD). As this will always be positive, the value of λ_1 will also always be positive. Hence, the days-at-sea constraint will always be binding.

The value of λ_1 can be substituted into equation 3.45, giving[18]

$$(3.48)\quad \lambda_3 = \frac{N}{y}\left\{\sum_i\left[(p_i - cl_i)a_iy\right] - CE'(E) - APD\right\} + \sum_i\lambda_{2,i}a_i$$

This in turn can be substituted into equation 3.46, giving

---

[17] These are known as the Kuhn-Tucker conditions (see Chaing 1984 for further details).

[18] If the hold constraint is not binding, then the discard constraint (equation 3.42) will also not be binding as the discards will be less than the catch (if not zero). Hence both $\lambda_{2,i}$ and λ_3 will be zero. In such a case the average trip profit will be equivalent to the marginal trip profit, as illustrated by equation (3.48).

$$\lambda_{2,i} = -N(p_i - cl_i + c_d) + \frac{N}{y}\left\{\sum_i\left[(p_i - cl_i)a_i y\right] - CE'(E) - APD\right\} + \sum_i \lambda_{2,i}a_i \tag{3.49}$$

From equation (3.49), the catch of a size class i will be discarded if $\lambda_{2,i}$ is positive. If the hold constraint is not binding (such that $\lambda_3 = 0$), then $\lambda_{2,i}$ is only positive if the net price (p_i-cl_i) is less than the cost of discarding, c_d. This condition is the same as that encountered earlier in the analysis of the unregulated fishery.

Evaluating the shadow value of discarding when the hold constraint is binding is less straightforward due to the summation involving the shadow values of all grades on the right hand side. For the purpose of simplification, assume that there are only two grades (or two species, as in the example of the unregulated fishery) with the lower grade possibly discarded. The shadow value of the retained species will hence be zero. Given this the shadow value for the discarded species (or grade) can be evaluated as:

$$\lambda_{2,1} = N\left[(p_2 - cl_2) - (p_i - cl_1)\right] - \frac{N}{(1-a_1)}\left[c_d + CE'(E) + APD\right] \tag{3.50}$$

In such a case, the lower valued species would be discarded (i.e. $\lambda_{2,1}$ would be greater than zero) if the costs associated with discarding was less than the net price difference between the species. The costs associated with discarding including the actual cost of disposing of the fish, the marginal cost of effort in recapturing the higher value fish and the proportion of the average profit per day at sea forgone, evaluated with zero discarding. The condition can therefore be given as

$$\frac{1}{(1-a_1)}\left[c_d + CE'(E) + APD\right] < \left[(p_2 - cl_2) - (p_i - cl_1)\right] \tag{3.51}$$

This is slightly different from the condition established in the unregulated fishery (equation 3.37) as the average trip profit becomes a component of the cost of discarding. The average profit per day at sea represents the opportunity cost of time spent fishing. This is because fishing time is limited by the regulation.

Hence days-at-sea restrictions may have two impacts on the level of discards. First, it may reduce the overall level of discards in the short run by reducing effort. The long run effects (provided effort does not expand through other means) may be higher or lower levels of discarding depending on the state of the stocks (see Figure 3.4). The policy may also alter the incentives to discard. The restriction on time that can be spent fishing increases the cost of effort by increasing the opportunity cost of time. In some cases, it may not be worth investing additional time to replace the discarded catch with higher valued species or grades. Hence a days-at-sea restriction may reduce the incentives to highgrade the catch to some extent.

3.4 Output controls

Output controls limit the quantity of fish that the fisher may land. Several forms of output controls are used in fisheries management. Restrictions on the amount of fish that can be landed each trip are imposed on some species in some fisheries. For other fisheries, limits on the quantity that can be landed over the year are imposed. These limits may be at the aggregate fishery level or the individual level. These various forms of output controls create different economic incentives for fishers to discard.

3.4.1 Trip limits

Trip limits are imposed in different fisheries for different reasons. In some fisheries, trip limits are imposed to slow the rate of fishing and thereby extend the fishing season throughout the year. Such a management system has been introduced in certain fisheries along the US Pacific coast, groundfish fisheries in New England and the west coast of Canada (Sampson 1994). A trip limit on Gulf of Maine cod was also introduced in May 1977 to slow the harvest rate (Dorsey 1977). In other fisheries, trip limits allow operators to land incidental catches of some species without providing an incentive to target the species. For example, in the Australian south east fishery trip limits on eastern gemfish allow fishers to land incidental catch but these are not sufficiently large to enable the fisher to land targeted catch of the species (Pascoe 1994).

With any form of output control, any catch taken above the maximum allowable level of landings must be discarded. This is also true for trip limits. Landing fish above the limit makes the fisher subject to penalties prescribed under the regulation. These may include fines or, in extreme cases, forfeiture of boat and fishing gear.

Trip limits may not always be imposed by fisheries management, but in some cases may be imposed by processors or dealers (Sampson 1994). Again using the Australian south east fishery as an example, individual trip limits on landings of whiting by danish seiners were imposed prior to the introduction of formal individual quotas by the main co-operative that handled the catch(Pascoe 1993). These limits reflected the contracted sales that the co-operative had already arranged.

The effect of the trip limit on the level of discarding depends on the ability of fishers to vary their catch composition by fishing in different locations. Sampson (1994) developed a model of fishing location choice where the limit on the level of landings of a species was a main component affecting location choice and the level of discards.

Following Sampson (1994), assume that there are two species with commercial value that are harvested by a single operator. The biomass of each species is assumed to be normally distributed with distance from port, the density of each species at location d being given by

$$(3.52) \qquad D_{i,d} = \frac{B_i}{\sigma_i \sqrt{2\pi}} \exp\left[\frac{-(d-\mu_i)^2}{2\sigma_i^2}\right]$$

where $D_{i,d}$ is the density of species i at location d, B_i is the total biomass of species i, π is Pi (i.e. 3.14152), μ_i controls the location of the peak biomass density of species i and σ_i controls whether the species is widely or narrowly spread[19].

The catch from any particular location is a function of the density at that location and the level of effort applied to the location. The catch of each species can be given by:

$$(3.53) \qquad C_{i,d} = q_i D_{i,d} F_d$$

where $C_{i,d}$ is the catch of species i at location d, q_i is the catchability coefficient of species i and F_d is the total fishing time spend at location d. For simplicity, it will be assumed that the fisher will fish only at one location each trip[20].

The fish that are caught may require time to handle before the gear can be re-deployed. This will include time spent sorting the catch as well as any preliminary processing (e.g. icing, boxing, gutting, heading or gilling etc.). The time handling the fish can be given by:

$$(3.54) \qquad H_d = \sum_i h_i C_{i,d}$$

where H_d is the handling time involved with the catch taken in location d and h_i is the handling time associated with each species i.

The time taken to reach the fishing location is a function of the distance travelled and the speed of the boat. The steaming time to and from the fishing location can hence be expressed as:

$$(3.55) \qquad S_d = 2d/V$$

where S_d is the total steaming time (including the return trip) and V is the speed (velocity) of the boat.

For most boats, the trip length is predetermined. Trip length may be limited by lack of refrigeration or accommodation for the crew. For example, small boats in the English Channel generally have trip lengths of only one day (or overnight) as they do not have room for ice nor ice-making facilities, generally do not have refrigerated holds and have no room for crew to sleep. In contrast, larger boats may have trips lasting several days as they have facilities to both store the fish and accommodate the crew (Pascoe 1997).

---

[19] For example, a dispersed species is widely spread whereas an aggregating species is narrowly spread. The smaller the value of σ_i the greater the density at any one point.

[20] Sampson (1994) extended to analysis to include multiple fishing locations and found that there may be additional benefits in fishing at more than one location.

The available fishing time is limited by the total trip length, the time spent steaming to and from the location and the time spent handling the fish. This can be given by:

$$(3.56) \qquad F_d = T - S_d - H_d$$

where T is the total trip length. Substituting in the expressions for steaming and handling time, the time available for fishing can be expressed as a function of fish stock density and speed of the boat. That is,

$$(3.57) \qquad F_d = \frac{T - 2d/V}{1 + \sum_i h_i q_i D_{i,d}}$$

Revenue from fishing can be expressed as a function of price and catch. For most individual fishers, the price received is exogenously determined as each individual does not contribute a large enough quantity to affect the price. Hence, the revenue from fishing can be given by:

$$(3.58) \qquad R_d = \sum_i p_i q_i D_{i,d} F_d$$

where p_i is the price received for species i and R_d is the revenue obtained from fishing in location d. Where a trip limit is in place on one of the two species (say species A), then the revenue is given by

$$(3.59) \qquad R_d = p_A \min(Q_A, q_A D_{A,d} F_d) + p_B q_B D_{B,d} F_d$$

where Q_A is the trip limit on species A. Hence, if the catch is less than Q_A the revenue is based on the total catch of species A. However, if the catch is greater than Q_A, the fisher can only land Q_A and the remainder ($q_A D_{A,d} F_d - Q_A$) is discarded.

Total trip costs consist of fuel costs, crew costs and other costs such as ice, food, etc. Fuel is assumed to be consumed at different rates when steaming, fishing and handling the fish. Crew costs are assumed to be based on a wage rate so depend on total trip length[21]. Other costs are assumed to be fixed on a per trip basis. Given these assumptions, total fishing costs can be expressed by:

$$(3.60) \qquad K_d = p_f (f_S S_d + f_F F_d + f_H H_d) + wT + O$$

where K_d is the cost associated with fishing in location d, p_f is the unit price of fuel, f_S, f_F and f_H are the rates of fuel use associated with steaming, fishing and handling respectively, w is the wage rate and O is the other trip costs. Total trip profits are given by:

$$(3.61) \qquad \pi_d = R_d - K_d$$

---

[21] In most fisheries crew are paid on a share basis, and hence are related to the level of catch. However, for simplicity (and to remain consistent with the analysis of Sampson (1994)), crew costs will be assumed to be independent of the catch rate.

The effect of the trip limit on discards will depend on the characteristics of the species and the costs of fishing. Following the example in Sampson (1994), the effects of a trip limit on discarding was estimated for two stocks that overlap, but have peak densities spatially separated. The parameters used in the model are given in Table 3.1.

Table 3.1 Parameters used in trip-limit model

	Species A	Species B
Species specific parameters		
• Biomass (B)	3000	3000
• Location peak μ	30	70
• Dispersion σ	30	30
• Catchability	0.02	0.02
• Handling time	0.5	0.5
• Price	6	12
Other parameters		
• Fuel price	1	
• Wage rate	1	
• Other costs	0	
• Vessel speed	8	
• Fuel use steaming	1	
• Fuel use fishing	2	
• Trip time	24	

Source: Sampson (1994)

Varying the trip limit for species A from 10 units per trip to 0 units per trip results in a change in the optimal fishing location as well as varying levels of discards (Table 3.2). Without a binding trip limit constraint (e.g. 8 or 10 units/trip), the optimal fishing location is 35 km from the port, landing 7.5 units of species A and 3.9 units of species B. Reducing the trip limit to 6 units/trip pushes the profit maximising fisher further offshore, resulting in lower catches of species A and higher catches of species B. With a low or zero trip limit, the fisher operates at the location that maximises the catch of the unconstrained species (Figure 3.6).

Table 3.2 Summary results from simulation model

	Trip limit for species A (units/trip)					
	0	2	4	6	8	10
Distance (km)	50	50	50	40	35	35
Profit	3.26	15.3	27.3	34.9	39.6	39.6
Catch A	4.5	4.5	4.5	6.5	7.5	7.5
Catch B	4.5	4.5	4.5	4.2	3.9	3.9
Discards of A	4.5	2.5	0.5	0.5	0	0

By changing location, the potential discarding is also reduced. Catches of species A fell from 7.5 units/trip before the limit to 4.5 units/trip with a zero trip limit. Had the operator remained fishing in the same location, discards would have been 7.5 units rather than 4.5 units.

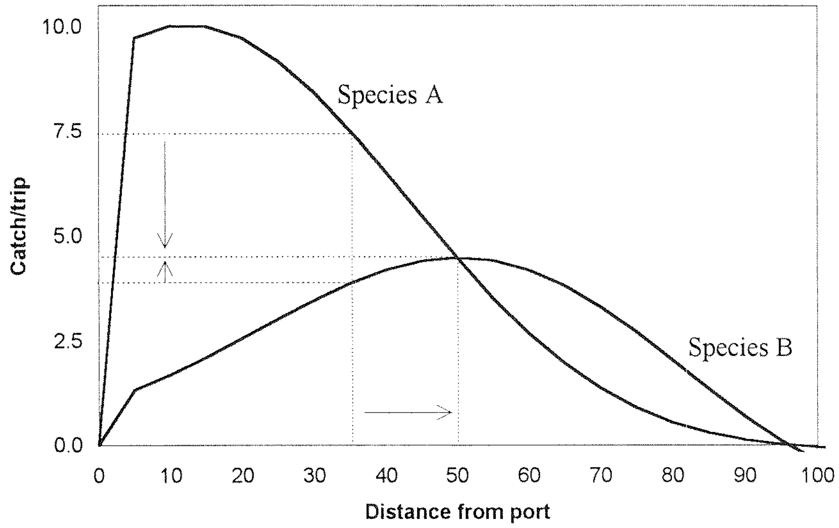


Figure 3.6 Spatial distributions of catch and effects of trip limit on fishing location

As noted above, the degree of discarding is determined by the characteristics of the stock and the ability of the fisher to adjust their fishing operations. If the stocks of the two species overlapped to a greater degree than indicated in this example, then the benefits of changing locations would have been significantly less. Hence, discarding would have been higher. For example, in Figure 3.7[22], the optimal fishing location is 45 km from port with or without a binding trip limit on species A. In such a case, the trip limit would not affect the location choice of the fisher, and all catch above the trip limit would be discarded.

Hence, a trip limit can lead to increased discarding in a multispecies fishery. However, if the stocks are fairly well separated in terms of abundance, a trip limit may also affect the fishing location used by the fishers. In such cases, the increase in discarding may not be as great as if the stocks overlapped to a larger extent.

---

[22] The *m* parameter for species A was changed from 30 to 65 to produce the new spatial distribution. All other parameters remain the same as in Table 3.1.

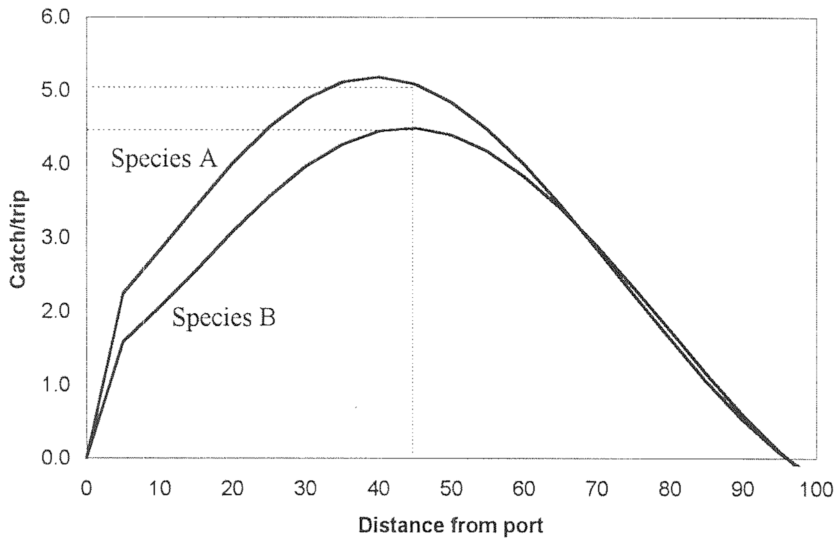


Figure 3.7 Similar spatial distributions of catch and optimal fishing location

3.4.2 Aggregate quota

A second form of output control is the aggregate total allowable catch. This has been used in many fisheries and is currently the main management measure of the European Common Fisheries Policy (Holden 1994). With aggregate quotas, the total quantity of fish that can be landed over the year (or season) is limited. Any catch above this limit must therefor be discarded.

The incentives to discard created under an aggregate quota system varies over the fishing season. Before the aggregate quota is exceeded, the fisher has the same incentive to discard as under an unregulated fishery. In the absence of any hold constraint, discards of low valued grades will occur if the net price received by landing them is negative (i.e. there is a net cost incurred by the fisher in landing the fish), and this is less (i.e. more negative) than the cost of discarding them. As most boats will have a hold constraint, at least on some trips, the incentive to highgrade will be greater, as previously outlined.

Once the aggregate quota has been reached, the fisher faces the same incentives as those under the trip limit regulation outlined above. Effectively, the trip limit will be zero for the species that has zero quota remaining. In most fisheries, the proportion of trips that are subject to zero trip limit is beyond the control of individual fishers. Evidence from most fisheries where aggregate quotas have been imposed indicates that the imposition of a global quota encourages fishers to increase effort during the time that quota is available in order to maximise their individual share of the quota. For example, in the US Pacific Halibut fishery, the race to fish and concomitant increases in effort resulted in the season length going from months to hours (Hilborn and Walters 1992). Similar 'race-to-fish' behaviour was observed in the Australian gemfish fishery prior to individual quotas being assigned (Pascoe 1993).

As there is no incentives for individuals to plan their harvest strategy over the year, fishers will operate in a manner that maximises their profits prior to the quota being reached, then operate in a manner that maximises profits with the zero trip limit. These decisions are mutually exclusive and depend on the conditions in existence on each trip (i.e. the existence or absence of the trip limit). For example, using the Sampson (1994) model outlined above, profit maximising fishers would operate 35 km from shore until the total allowable catch was reached. This is the unconstrained location and is the same location that the fisher would operate in an unregulated fishery. However, once the total allowable catch was taken, the fisher would then move further offshore to the 50 km area (Table 3.2). This is the profit maximising fishing location given that they cannot land any more of the restricted species. At this location, considerable quantities of the restricted species are still caught as bycatch and discarded.

Theoretically, all over-quota catch will be discarded regardless of price. In practice, some of this catch will be landed illegally as either undeclared catch or mis-reported catch. The incentives to land catch illegally will depend on the expected net price received (price less handling and landing costs), the probability of being caught and the magnitude of the expected fine (Sutinen and Anderson 1985)[23].

3.4.3 Individual transferable quotas

Individual transferable quotas (ITQs) involve landing limits on individual fishers rather than on the fishery as a whole. While the potential economic benefits of such a system have been widely recognised (see for example, Squires, Kirkley and Tisdell 1995, Hannesson 1996), the system has also been criticised for the incentives it creates to discard fish (Copes 1986).

With individual quotas, fishers are permitted to land only a certain quantity of each quota species given by their quota holdings. Like the aggregate quota, a total allowable catch is determined for each species to be managed. This total quota, however, is subdivided into disaggregated units which are allocated to individual fishers to remove the need to race for fish. These individual quotas can then be traded between fishers, so that each fisher can adjust his or her quota holdings to best suit their fishing operation.

ITQs can lead to three forms of discarding: discards of over-quota catch, highgrading and price dumping (Copes 1996). These will be examined below.

---

[23] Sutinen and Kuperan (1995) extended this analysis to include other sociological factors that can affect the fishers' willingness to comply with regulations. This includes perceptions of morality, legitimacy of the regulation and social influences.

Discards of over-quota catch

Catches of quota species that are not covered by the fisher's quota holdings must be discarded. These species may not be covered by the fisher's quota holdings if the fisher has already filled his or her quota for that species or has never held quota for that species. In theory, ITQs can address this problem through quota trading. That is, either by purchase or lease of additional quota (Dewees 1990). In many cases, however, the fisher is unable (or unwilling) to buy or lease more quota. This might be because the total allowable catch has been taken or the trading price for quota is greater than the fisher is willing to pay.

Another reason for failing to purchase quota to cover over-quota catch relates to imperfections in the quota market (Baulch and Pascoe 1992). The fisher has to find the additional quota before landing the fish and hence while still at sea. With trips of limited length and poorly established quota markets in many ITQ fisheries, finding quota during the return voyage is difficult. If the fisher is unable to find quota then he or she may face prosecution if caught landing the fish. Faced with this risk, many fishers would choose to discard the fish rather than attempt to find quota and possibly fail.

Fishers respond to over-quota catch in the same manner in the analysis of the trip limit in the previous sections. When the quota of one of the species is finished, the fisher will fish in the location where profits are maximised excluding the revenue from the over-quota species. This may result in a reduction in the catch of the over-quota species as in the examples above. However, if the over-quota catch is of a species that is relatively minor in the fishers' normal fishing operations then running out of quota may not necessarily induce them to change fishing location.

Unlike the aggregate quota situation where the fisher does not have control over when the zero trip limit is imposed, the fisher under an ITQ system is better able to plan the use of their quota over the year. The fisher will choose the fishing strategy that maximises their profits over the year, subject to the management, environmental and social constraints they face. This may also involve an overall reduction in discards compared with the aggregate quota system. Wilen (1990) suggests that, at least in a number of fisheries, bycatch problems are reduced (if not eliminated) under ITQs. Discards of all species by Alaskan sablefish vessels was found from 24.5 per cent of the catch to 11.7 per cent of the catch following the introduction of ITQs, suggesting that fishers are better able to avoid unwanted species in the ITQ fishery (Warren *et al* 1997).

Highgrading

Fishers have an increased incentive to highgrade under ITQs (Anderson 1994). Both Anderson (1994) and Vestergaard (1996) estimated the set of conditions under which highgrading would increase in an ITQ fishery. Anderson (1994) assumed for simplicity that hold constraints are not binding, while Vestergaard (1996) incorporated hold constraints into the analysis.

Following Vestergaard (1996) and assuming (for simplicity) a single species fishery comprised of several size grades, the total catch that can be taken by the fisher is limited by the quota constraint, Q, such that

$$(3.62) \qquad N\sum_{i}(a_i yE - D_i) \leq Q$$

where again N is the number of trips, a_i is the proportion of the catch of size class i, y is the catch per unit of effort, E is the level of effort and D_i is the level of discards of size class i. As quota can be traded, the catch is constrained by the final level of quota held which may differ from the initial allocation, $\overline{Q}$. Quota can be either purchased or leased in on an annual basis. For simplicity, it is assumed that the cost of these are the same on an annual basis[24].

The profits that can be obtained from fishing over the year as a whole can be given by

$$(3.63) \qquad \pi = N\left\{\sum_{i}\left[np_i(a_i yE - D_i) - c_d D_i\right] - CE(E)\right\} - s(Q - \overline{Q}) - F$$

where np_i is the net price received for size class i (that is, price less the cost of landing the size class i), c_d is the cost of discarding one unit of catch, $CE(E)$ is the total cost of effort each trip (a function of the level of effort), F is the fixed costs associated with the fishing vessel and s is the average annualised price of quota. Hence $s(Q - \overline{Q})$ represents the costs (or benefits) of buying (or selling) quota.

As well as the quota constraint, the fisher may also be subject to a hold constraint, given by

$$(3.63) \qquad \sum_{i} a_i yE - D_i \leq B$$

where B is the hold constraint. As before, a further constraint is added to the model for completeness to ensure that the level of discards cannot exceed the quantity caught, given by:

$$(3.64) \qquad a_i yE - D_i \geq 0$$

As in the previous analysis, the Lagrangian function can be represented by

---

[24] In theory, the purchase price of quota should reflect the net present value of the long run average resource rent associated with a unit of quota. This would include the cost of capturing the fish. The lease price should reflect the annualised cost of this value, and hence theoretically should be equivalent on an annual basis. In practice, however, the lease price is likely to reflect the short run marginal value of an additional unit of quota. The marginal value of a unit of quota for fish that has been caught will be the price of the fish less the cost of landing it. Hence the lease cost could be substantially higher than the annualised purchase price, particularly at the end of the season when the demand for leased quota may exceed the supply.

$$L = N\left\{\sum_i \left[np_i(a_i yE - D_i) - c_d D_i\right] - CE(E)\right\} - s(Q - \overline{Q}) - F$$

(3.65) $$+\lambda_1\left(Q - N\sum_i (a_i yE - D_i)\right)$$

$$+\sum_i \lambda_{2,i}\left(a_i yE - D_i\right) + \lambda_3\left[B - \sum_i \left(a_i yE - D_i\right)\right]$$

where λ_1 is the shadow price of an additional unit of quota, $\lambda_{2,i}$ is the shadow price associated with the discarding constraint for each size class i and λ_3 is the shadow price of an additional unit of hold capacity. Differentiating this function with respect to the number of trips, the length of each trip, the level of discarding and the amount of quota held results in the necessary conditions for profit maximisation:

(3.66) $$\frac{\partial L}{\partial N} = \sum_i \left[np_i\left(a_i yE - D_i\right) - c_d D_i\right] - CE(E) - \lambda_1\left(\sum_i (a_i yE - D_i)\right) \leq 0$$

(3.67) $$\frac{\partial L}{\partial E} = N\sum_i \left[np_i a_i y - CE'(E)\right] - \lambda_1 N\sum_i a_i y + \sum_i \lambda_{2,i} a_i y - \lambda_3 \sum_i a_i y \leq 0$$

(3.68) $$\frac{\partial L}{\partial D_i} = -N(np_i + c_d) + \lambda_1 N - \lambda_{2,i} + \lambda_3 \leq 0 \text{ for each size class i}$$

(3.69) $$\frac{\partial L}{\partial Q} = -s + \lambda_1 \leq 0$$

From the Kuhn-Tucker conditions, if N, E, D and Q are greater than zero (as would be expected), the four inequalities in equations 3.66 to 3.69 can be replaced with equal signs. From equation 3.69, the fishing operation is at an optimum when the shadow value of a unit of quota is the average annualised price of quota. From equation 3.66, the shadow value of a unit of quota is also equivalent to the average short run profit[25] per unit of landings. This is obtained by rearranging equation 3.66, giving

(3.70) $$\lambda_1 = \frac{\sum_i \left[np_i\left(a_i yE - D_i\right) - c_d D_i\right] - CE(E)}{\left(\sum_i (a_i yE - D_i)\right)}$$

From this, if the price of quota is less than the average profit per unit of landings, then it is worthwhile buying more quota.

If the fisher is not constrained by the hold capacity, such that $\lambda_3 = 0$, then from equation 3.68, the shadow price associated with discarding size class i ($\lambda_{2,i}$) is given by

[25] This is the short run profit as it excludes fixed costs associated with the boat.

$$(3.71) \quad \lambda_{2,i} = -N(np_i + c_d) + SN$$

Discarding is worthwhile only if $\lambda_{2,i}$ is positive. In such a case, equation 3.71 can be expressed as

$$(3.72) \quad s \geq (np_i + c_d)$$

From this, if the price of quota is greater than the net price received plus the cost of discarding (effectively representing the opportunity cost of landing the size class i and the cost of discarding it), then the fisher is better of discarding the fish than landing it and using the quota to land more of the higher grade (Anderson 1994, Vestergaard 1996). If the hold constraint is binding, then the condition for discarding becomes

$$(3.73) \quad s \geq (np_i + c_d) - \lambda_3 / N$$

As λ_3 will be positive if the constraint is binding, it is likely that this condition will hold for more grades than if the hold constraint is not binding. Hence a higher level of discards could be expected when both quota and hold constraints are binding.

Arnason (1995) noted, however, that fishers are able to change their gear and hence alter the size composition of their catch. The incentives to do this were examined under conditions of free and open access earlier. These incentives are also affected by the use of ITQs.

Following Arnason (1995), the profit function in equation 3.21 used earlier can be redefined to include the effects of ITQs.

$$(3.74) \quad \begin{aligned} \pi(e,d,x,p) &= \sum_i (p_i - CL_i - \Omega)[C_i(e,x,i).(1-a_i) - d_i] - CE(e) \\ &\quad - \sum_i CD_i(d_i) - \sum_i CS_i(a_i) \end{aligned}$$

where p_i is the price received for size class i, CL_i is the unit cost of landing[26] size class i, Ω is the opportunity cost of quota (i.e. the value of the quota consumed by landing the size class i), $C_i(e,x,i)$ is the total catch of grade i, $CE(e)$ is the cost of effort, taken as a function of the level of effort, e, and $CD_i(d_i)$ is the discard cost function. Associated with the gear is a selectivity cost function, $CS_i(a_i)$, which is a function of the selectivity parameter a_i.

Differentiating this profit function with respect to effort, discards and selectivity results in the necessary first order conditions for profit maximisation by the fisher:

$$(3.75) \quad \sum_i (p_i - CL_i - \Omega)[C_i'(e,x,i).(1-a_i)] = CE'(e)$$

---

[26] In the earlier analysis this was assumed to vary with the level of landings. For simplicity, it will be assumed to be a constant unit cost.

$$(3.76)\quad -[p_i - CL_i - \Omega] \leq CD_i'(d_i)$$

$$(3.77)\quad -[p_i - CL_i - \Omega]C_i(e,x,i) \leq CS_i'(a_i)$$

These conditions are similar to those in equations 3.22 to 3.24 in the earlier analysis, with the exception that the opportunity cost of quota has become an important component of the conditions. From the first condition, a profit maximising producer will continue to apply effort to the fishery until the marginal benefit of fishing (the revenue from catching the marginal fish less the cost of landing the marginal fish) is equal to the marginal cost of the additional unit of effort evaluated at the total effort level, e, (i.e. $CE'(e)$). The benefit from applying effort is now less than before as the fisher has the option of selling the quota rather than catching the fish.

The second condition is a restatement of the previous condition in equation (3.18). A net cost must be incurred by landing the fish (i.e. the landing costs exceed the price received) and this must be greater than the cost of discarding before discarding is an optimal option. The final condition indicates that in order to employ more selective gear rather than discard, the net benefits received from landing the size class i (this is the net price including the opportunity cost of the fish landed times the quantity caught, assuming no discards) must be both negative and less than the marginal cost associated with achieving that level of selectivity.

The optimal combination of selectivity and discarding will change with the introduction of ITQs due to the effects of the opportunity cost of using the quota to land small fish. In Figure 3.8, the marginal cost of discarding and selectivity intersect the benefits of not landing (the negative of the net price) at d and a respectively for the unregulated fishery. From this, the optimal selectivity will be a, and the proportion discarded (after selectivity) will be d. Hence, the quantity of discards of grade i would be $C_i(e,x,i).(1-a).d$ (Arnason 1995).

The introduction of ITQs changes the incentives to adapt selective gear and discard as discussed above. The additional opportunity cost of quota results in the optimal level of discards rising to d_1, but also results in an increase in the use of selective gear to a_1. Hence the new quantity of discards would be $C_i(e,x,i).(1-a_1).d_1$. As a_1 is greater than a, less smaller fish would be caught under ITQs. However, as d_1 is greater than d, a higher proportion of the smaller fish that were caught would be discarded under ITQs than under open access.

The net effect of the introduction of ITQs could therefore be to either increase or decrease discarding, taking into account the incentive to change gear selectivity. For example (following Arnason 1995), if the initial discard and selectivity parameters were 0.4 and 0.5 respectively, and the new selectivity parameters were 0.6 and 0.7 respectively, then the level of discards changes from $D=0.2C$ to $D=0.18C$. Hence, in this example, the introduction of ITQs would lead to a reduction in highgrading.

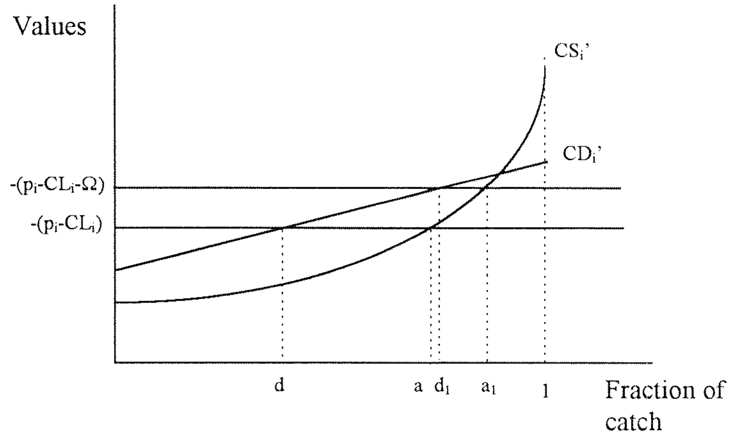


Figure 3.8 Optimal discarding and selectivity
Source: Arnason (1995)

Price dumping

Price dumping (Copes 1996) occurs where all of the catch of a species is discarded in response to the expected price received. This is an extreme form of highgrading related to the quota constraint.

Price dumping may occur as a result of adverse price fluctuations day to day (or within a day). On the return journey to port, a fisher may hear that prices have fallen for the key quota species that they are preparing to land. As a result, the fisher may discard the catch of that species in anticipation of saving the quota for use on other days when the price is higher. Such behaviour has been observed in the British Columbia sablefish fishery (Copes 1996).

As the opportunity cost of the quota is related to the average profit per unit of fish landed (see above), a lower than expected price may well result in the condition expressed in equation 3.76 holding for all grades. That is, the net price less the opportunity cost of the quota may be negative for all grades, and this may be less than the marginal discard cost. In such circumstances, the profit maximising fisher would discard his or her catch, as the quota could be used more profitably by landing more fish when the price was higher or leased out to other fishers.

Such a problem would not occur in many fisheries as it would require the price of the species to be highly sensitive to the quantities landed. As the opportunity cost of quota also takes into account the cost of harvest (and is hence below the expected price), the price would need to fall substantially before it was rational to discard the entire catch. Further, discarding the entire catch on a regular basis would greatly reduce the average profit per unit landed, and hence the opportunity cost of the quota would also be lower. As a result, the problem is partly self correcting if it occurs on a regular basis.

3.5 Chapter summary

Bycatch occurs because different species are caught together as a result of the non-selectiveness of the gear. These species may be commercial species or non-commercial species. Where technical interactions exist between species, the resultant population size of any particular species is a function of the price of itself and the other species with which it is caught, as well as a function of the growth rate of itself and the other species. In some cases, a species – either commercial or non-commercial – could be driven to extinction if it is caught primarily as bycatch in association with another species. This could occur even if the bycatch species were not discarded, but was landed and sold on the market.

In an unregulated fishery (i.e. free and open access), fishers have an incentive to discard smaller sized fish if the expected net price (that is, the price less landing costs) is negative and the resultant cost incurred in landing the fish are greater than the costs incurred in discarding the fish. This is termed highgrading. Small fish often do not receive a high price on the market relative to larger fish of the same species.

The incentives to discard in an unregulated fishery are increased if the boat has a limited hold capacity. In such cases, it is rational to discard low valued sizes and also low valued species in order to utilise the hold for the more valuable sized fish or the more valuable species.

The introduction of limited entry does not change these incentives to discard. However, if the effort level is reduced as a result of the licence restrictions, then there may be a short run reduction in the level of discarding. However, in the long run, discarding may increase if the stock of the bycatch species increases. In such a case, the discarding is associated with a higher stock and, from a conservation perspective, may be more desirable than when discarding (and stock size) was lower.

Minimum landing sizes may lead to increased discarding as all catch below the minimum size must be discarded. Minimum landing sizes are introduced in order to encourage fishers to avoid the capture of small fish, hence increasing the survival of these fish. This, theoretically, can lead to larger biomass and larger spawning stocks. However, the effect of the policy on the level of catch and discards of the small size classes will depend on which size classes would be caught and discarded in an unrestricted fishery.

Days at sea restrictions can also lead to a reduction in the level of discards. Days-at-sea restrictions may have two impacts on the level of discards. First, it may reduce the overall level of discards in the short run by reducing effort. As in the case of limited entry, however, the long run effects may be higher or lower levels of discarding depending on the state of the stocks. Second, the policy may change the costs facing the fisher and thereby alter the incentives to discard. The restriction on time that can be spent fishing creates an opportunity cost of time. In some cases, it may not be worth investing additional time to replace the discarded catch with higher valued species or grades.

Trip limits can result in an increase in discards as all catch over and above the limit must be discarded. The trip limit can, however, provide an incentive to change fishing location in order to catch a greater proportion of the unrestricted species. Hence, total catch of the restricted species may be reduced even though discards may increase.

Under an aggregate quota system, the incentives to discard change depending on whether or not the quota has been reached. Before the total allowable catch is reached, the incentives to discard are the same as those under free and open access. That is, small fish or lower valued species may be discarded if their net price is negative, and/or if the hold constraint is binding. Once the total allowable catch is reached, the fisher is faced by the same incentives as under the trip limit (as essentially the trip limit for the restricted quota species is zero). In some cases, this might result in a change in fishing location. It is likely, however, that the restricted species will still be caught and discarded.

Individual transferable quotas can result in additional incentives to discard, but can also result in lower levels of discarding. Under an ITQ system, a fisher is better able to plan his or her harvesting strategy. This could result in a fishing pattern that lowers discards or increases them, depending on the spatial distribution of the stock. The opportunity cost associated with the quota can also change the incentives to highgrade catch. While the incentive to discard is generally increased, the incentives to adopt more selective gear is also increased. Hence, while a greater proportion of the catch of small fish may be discarded, less small fish may be caught and hence overall discards may be lower. The actual direction of change will vary from fishery to fishery.

From the above, discarding (including highgrading) is a feature of every fishery irrespective of the management system. The management system can, however, alter the incentives to discard. The extent and the direction of change in level of discard is, in many respects, more a function of the characteristics of the stocks being harvested than a function of the management plan.

4. Optimal discarding and externalities

The previous chapter considered the microeconomic incentives to discard unwanted catch faced by individual fishers. To the individual, the decision to discard is both rational and optimal provided that the conditions for discarding described in the previous chapter are satisfied. In the absence of any fishery regulation, discarding is a profit maximising activity to the individual fisher provided that the net price received by landing the fish is negative and less than the cost of discarding the fish at sea. Higher levels of discarding may be optimal at the individual fisher level if the hold capacity forms a binding constraint to the level of landings. The introduction of management regulations can also affect the incentives facing individual fishers.

From a broader perspective, however, discarding creates costs that are not considered by the individual fisher. This is because either the fishers do not incur these costs themselves, or the costs are the product of the activity of all fishers in the fishery and are hence outside the control of the individual. In this chapter, the affects of these costs on the optimal level of discarding from a societal perspective will be examined.

4.1 Externalities and discarding

An external effect, or externality, occurs when the production or consumption decisions of one individual affect the well-being of another in an unintended way, and no payment of compensation is made by the producer of the externality to the affected individual (Perman, Ma and McGilvray 1996). Both conditions are necessary for an externality to exist (Pearce and Turner 1990). If compensation is paid to the affected party, then the cost of the production or consumption decision has been internalised and nobody is worse off than they were before. Alternative terms for externalities include side-effects, spillovers, external diseconomies or social effects (Davis and Kamien 1977, Pearce and Turner 1990).

Externalities can be both positive and negative. A positive externality is one that produces unintended benefits to a third party. For example, the results of research can provide benefits to people or organisations other than those who paid for the research to be conducted. The most familiar form of negative externality is the costs created by pollution. In many industries, the production process involves the generation of a degree of waste products, either as smoke, water pollutants or noise. These pollutants create costs which are borne by society as a whole. These may be real (tangible) costs such as increased health costs (see for example Lave and Seskin 1977, Marakovitis and Considine 1996) or damage to property, or intangible costs such as loss of enjoyment of the natural environment or discomfort through increased noise levels. In such a case, the private and social costs of the activity diverge, and the profit maximising decisions of the producer are not socially efficient (Ruff 1977). These social costs are not taken into account during the production process (as the profit maximising producer considers only the costs and benefits accruing to him or herself), thus resulting in a level of production that may exceed the socially optimal level.

The taking and subsequent discarding of unwanted catch results in a number of externalities, some of which were discussed in the second chapter. These include both positive and negative externalities.

First, the taking of undersized or juvenile fish can produce several types of externality. As in the discussion of the minimum landing size in the previous chapter, catching undersized fish results in potential growth overfishing and recruitment overfishing. With growth overfishing, the juvenile fish could be taken at a later date at a larger, more valuable size. Hence, the overall potential yield of the fishery (and similarly the value of the yield) is reduced. With recruitment overfishing, the taking of juvenile fish reduces the potential spawning stock size, resulting in lower levels of future recruitment. The lower level of future recruitment affects all fishers in the fishery. Hence the act of catching juvenile fish not only affects the potential future benefit to the fisher him or herself, but all other fishers as well. Discarding of juvenile yellowtail flounder in the southern New England trawl fishery was estimated to cost the industry \$15 million a year in forgone profits and crew incomes (Edwards, Murawski and Thunberg 1997).

Reducing the potential level of landings can also affect consumers through a reduction in consumer surplus. Consumer surplus is the area under the demand curve and above the price received. A loss in consumer surplus can occur through a reduced quantity of landings which increases the price to consumers. The loss is related to the responsiveness of price to quantity landed (the price flexibility). If prices are inflexible with respect to quantity landed, then varying the quantity landed will not affect the price received. Consumer surplus in such cases is zero for all levels of landing. However, if prices do respond to the quantity landed, then a reduction in landings will result in an increase in price and a loss of consumer surplus. The discarding of juvenile yellowtail flounder in the southern New England trawl fishery mentioned above was also estimated to cost consumers \$11 million a year in terms of lost consumer surplus (Edwards, Murawski and Thunberg 1997).

The taking of juvenile fish in one fishery can also impinge on the potential profits in other fisheries. As seen in Chapter 2, bycatch of juvenile fish in several shrimp fisheries reduces the potential yield in other fisheries that target these species. For example, in the inshore shrimp fishery based in The Wash on the east coast of England, bycatch of juvenile sole and plaice are estimated to cost the targeted sole and plaice fishery somewhere in the order of £3.4 million a year (Revill 1997). Each tonne of bycatch of halibut in the Alaska groundfish fishery is estimated to reduce the potential yield of the targeted halibut fishery by 1.8 tonnes, the discounted net benefit of which was estimated to be \$2,461 (Terry 1997). Based on the estimated bycatch rates in the groundfish fishery, the cost to halibut fishers of bycatch in the groundfish fishery was estimated to be about $16.7 million (Terry 1997).

Discarding over-quota fish (whether as the result of a global quota, individual quota or trip limit) also produces external costs. A proportion of these fish could have potentially been caught in the next year, reducing the costs of fishing in order to achieve next year's quota. These costs are again incurred by all fishers in the fishery, including the fisher who discarded the over-quota catch.

Even where discarded species do not have a commercial value, discarding can still impose a negative externality. Resources, including fisheries resources, provide a broader set of services than is often recognised in economic analyses (Perman, Ma and McGilvray 1996). Species such as turtles and marine mammals[27] are believed to have an intrinsic value. These values may take a number of forms. Existence value is the benefit from knowing that a species exists, and is unrelated to any actual or potential use of the species (Pearce and Turner 1990). This may have a relatively constant total value irrespective of the size of the population. In such cases, the average value of an individual increases as the population declines. A second form of non-market value is option value. This is the value of preserving the resource for potential future consumption. This future 'consumption' could be the existence value conferred on future generations (termed the bequest value) or it could be a use value at some time in the future. Both types of value can be considered passive use value (Hoagland and Jin 1997) as the value of the resource is in its non-use.

Where the species reaches a threatened status, there may be a loss of existence value and option value as there is a possibility that the population may collapse and the species become extinct. The extinction of a species can cause considerable disutility[28].

While the value of threatened or endangered species is difficult to measure, an indication of the non-market value of such species can be gauged by the reaction of individuals to their death as a result of any bycatch and discarding. Bycatch of a number of species such as whales, dolphins, seals and turtles have attracted considerable public concern suggesting that the non-market value of these species may be high relative to the market value of the species with which they are caught. Bycatch and discarding of these species by fishers can therefore cause considerable external costs to the rest of society.

---

[27] Some marine mammals have an explicit market value. For example, whale meat attracts a market price in Japan and Norway. Similarly, dolphin is eaten in Sri Lanka and has a market price. However, in many countries these species do not have a market value.

[28] Economists generally consider benefits in terms of utility, which is the measure of satisfaction gained in the consumption of a good (Perman, Ma and McGilvray 1996). This utility can be expressed in monetary terms for market commodities. However, for non-market commodities a monetary value is not apparent. While estimates of the monetary equivalent value can be made through various techniques, it is common to refer to the benefits of non-market goods as creating utility. Disutility is the loss of utility associated with a non-market cost.

Discarding can also produce some positive externalities. As discussed in Chapter 2, discarding has been associated with increased seabird populations in some fisheries. This may result in some increase in utility to bird-watchers. In some shrimp fisheries, discards have been thought to have helped sustain a higher stock of shrimp (Sheridan *et al* 1984).

4.2 Economically optimal levels of discarding

The activity of discarding can be compared with the generation of pollution in that both are unintended by-products of the production process. Part of the cost of discarding bycatch is internalised (e.g. the cost of sorting and discarding of the catch) and part is external, as discussed above (Boyce 1996). Hence, the economic analysis of the optimal level of discarding is comparable to that of the optimal level of pollution.

The basis of most economic analyses is the concept of efficiency. This may be considered in terms of either productive or allocative efficiency. Production efficiency occurs when the available inputs are used to their full capacity, and increasing the production of one good can only occur by reducing the production of another good. Allocative efficiency (or Pareto efficiency) occurs when there is no better allocation of goods that makes at least some people better off without making others worse off (Varian 1990).

Unless the system is already at an efficient level, achieving an efficient allocation will involve reallocating resources between individuals[29]. This, however, will result in some individuals being made worse off than they previously were, while others are made better off. Provided the gains of those who benefit exceed the cost to those who lose from the reallocation, the reallocation is still considered a pareto improvement. The objective of society could be taken to be one of maximising the sum of benefits minus the sum of costs of all activities (Pearce and Turner 1990).

Discarding produces benefits in terms of the associated catch, and costs in terms of the externalities it produces. Based on the efficiency criteria above, the optimal level of discards would have to be that which maximised the net benefits of discarding, where the net benefit of discarding is equal to the benefit of the output with which the discarding is associated (that is, the value of the associated catch) less the damages resulting from the discarding (the externalities imposed on others) (Perman, Ma and McGilvray 1996).

The damages associated with discarding can be taken as a function of the level of discards, given by

$$(4.1) \qquad d_t = f(D_t)$$

---

[29] There is considerable literature on why the system may not automatically be at an efficient level. This largely relates to imperfections in the market for goods and services. Most microeconomics or natural resource economics textbooks cover this problem in detail.

where d_t is the damage in time t associated with the level of discards in time t, D_t. The benefits of discarding are related to the value of the associated production. Assuming that catch of the target species cannot be taken without incidental catch of the bycatch species, then the benefits of discarding can be expressed as a function of the profit generated by the level of catch of the target species, given as

$$(4.2) \qquad b_t = g(\pi_t)$$

where π_t is the profit from fishing in period t, a function of the level of catch and corresponding level of discarding. The net benefits of discarding then are given by

$$(4.3) \qquad NB_t = g(\pi_t) - f(D_t)$$

Net benefits are maximised when dNB/dD=0. From this, the condition for optimal discarding can be expressed as

$$(4.4) \qquad g'(\pi_t) = f'(D_t)$$

That is, the marginal benefit of discarding is equal to the marginal cost. This can be depicted graphically, as in Figure 4.1, assuming that marginal benefits decrease with increased levels of discarding and marginal costs increase. As the marginal cost of discarding is generally not incurred by the fisher, the profit maximising fisher would increase his or her individual level of discards until the conditions outlined in the previous chapter were satisfied. At such a point, the marginal benefit of discarding to the fisher would be zero as an further discarding would result in a decrease in income. Hence, in an unregulated fishery, the 'natural' level of discarding is likely to be D_n.

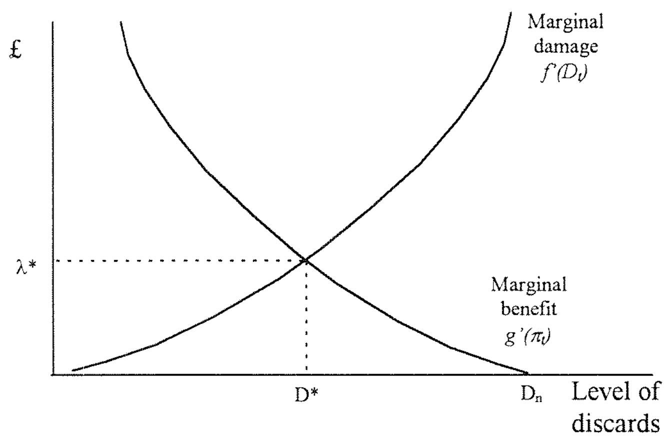


Figure 4.1 Optimal level of discarding

In contrast, the optimal level of discarding is D^*, given by the intersection of the marginal damage and marginal benefits curves. At levels of discarding below D^*, the total benefits to society could be increased by increasing the level of activity that creates the discarding. At levels of discarding above D^*, the marginal costs of discarding exceed the marginal benefits and total benefits to society can be increased by decreasing the level of discarding.

The value λ^* is the shadow price of discarding. This is the hypothetical price of discarding at which the individuals being affected by the discarding should be willing to pay to reduce the level of discarding by an additional unit, assuming a market existed to allow such a transaction (Perman, Ma and McGilvray 1996), or the price that they should be willing to be compensated if discarding was to increase. This equates to the price that the fisher should be willing to pay to discard an extra unit of fish. However, a market for such transactions generally does not exist (Pearce and Turner 1990).

A difficulty with the above analysis is that changes in fisheries management may change the shape of the marginal benefits curve. For example, in the previous chapter, it was demonstrated that output controls provide a different set of incentives to avoid bycatch and discarding than input controls. Hence the marginal benefits of discarding could vary depending on the type and level of regulation in place in the fishery. This difficulty can be overcome by incorporating any behavioural adjustments that take place as the discard level is varied (Perman, Ma and McGilvray 1996). However, as the adjustments will vary in response to the incentives created by management, there may exist a family of curves and a different optimal level of discarding under each management system.

A further difficulty with estimating the marginal benefits of discarding is that these differ substantially between the short and long term. In the short term, increasing effort will lead to an increase in the catch of the target species and an increase in the level of associated bycatch. Similarly, reducing the level of effort in the short term will reduce the level of catch and bycatch and hence discarding. Consequently, the short term marginal benefit curve will be similar to that in Figure 4.1. In the longer term, however, reducing the level of effort may result in an increase in the stocks of both the target and bycatch species. With higher stock levels, bycatch and discarding may be actually higher in the long term.

This is demonstrated in Figure 4.2. At the open access equilibrium level of effort, the level of discarding is D_{oae}. As this is an equilibrium position, the level is the same in both the short run and long run. Based on the criteria above, the optimal level of discarding is D_{sr}, which is produced by E^* effort. However, at the lower level of effort the stocks are able to recover so the long run sustainable catch (and hence discards) is D_{lr}. This may be greater than the initial level of discarding, as illustrated in Figure 4.2, but will not necessarily be. Associated with the new biomass will be a new short run catch-effort relationship and a new short run marginal benefit of discarding function.

An alternative way of assessing the optimal level of discarding is to consider the costs of reducing discarding rather than the benefits from discarding. Reducing the level of discarding is not cost-less. Reducing discarding requires increased enforcement in quota fisheries, and may impose additional costs on fishers if they are required to use equipment that reduces their technical efficiency. The marginal benefits of discarding curve can be replaced by a marginal cost of discard reduction curve. This is likely to be negligible at the unregulated level of discarding, but increase as the level of discarding decreases (that is, the level of discarding abatement increases).

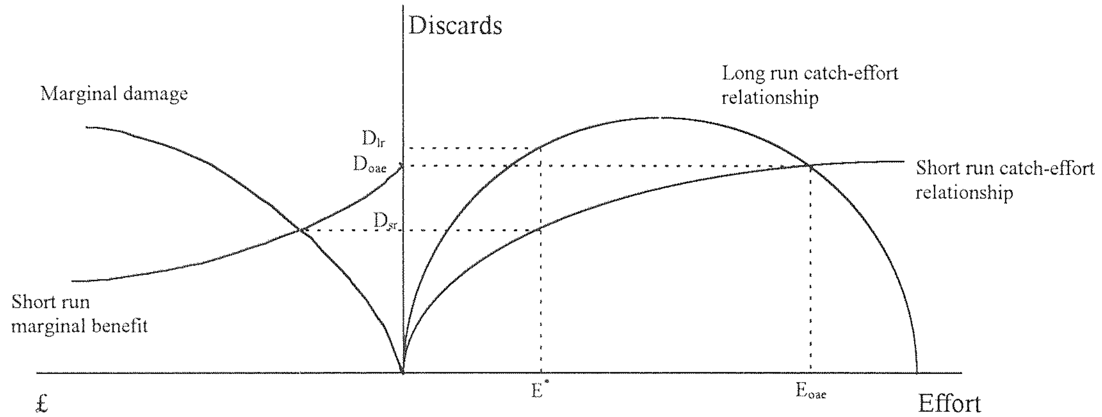


Figure 4.2 Long and short run levels of discards

In Figure 4.3, the optimal level of discarding is again D^*, with the optimal level of abatement being D_n-D^*. This is the level that minimises the combined area under the two costs curves (with the marginal abatement curve starting from D_n and increasing backwards as discarding decreases). The total cost incurred is the sum of the areas A and B. Any other level of discards would create a greater total cost, either by having a greater damage cost (if above D^*) or a greater abatement cost (if below D^*).

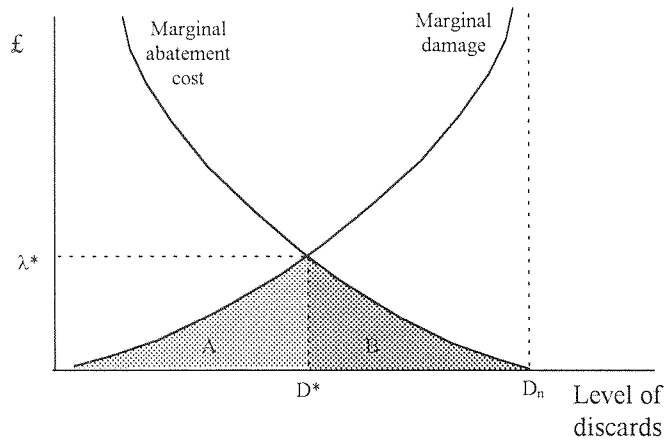


Figure 4.3 Optimal level of discarding based on abatement cost
(Derived from Perman, Ma and McGilvray 1996)

The relationship between the marginal abatement cost curve and the marginal benefit curve varies from fishery to fishery. If reducing the level of output was the only way of reducing discarding, then the two curves would equate as the marginal cost of abatement would equal the lost marginal benefit of production. However, there may be lower cost methods of reducing discarding. As mentioned above, changing the management system creates different incentives to discard, and different management systems may result in either an increase or decrease in discarding.

From the figures above, it is clear that the optimal level of discarding will be zero in only exceptional cases. One such case would be if fishers do not have any incentives to discard in the unregulated fishery. This would involve all species caught having a positive net price when landed and the hold capacity not limiting the level of landings from each trip. Such a fishery would be particularly rare. A second case would be if the discarding created no damage to any other person. This includes other fishers in the same fishery, other fishers in other fisheries or others in the rest of society who may value the species being discarded and hence may experience some loss through the death of the animals following discarding. Where all discards are returned to the sea alive and in good condition such a condition may hold. However, for most fisheries there is likely to be some damage caused through discarding. A final condition for zero optimal discarding would be a zero cost of discard abatement. This would involve no costs to society (including the fishers themselves) by reducing the physical level of discards and no enforcement costs. Such a condition could hold, but only if there were no incentives to discard in the first place as in the first condition.

Given this, some positive level of discarding is likely to be optimal in the majority of fisheries. Management policies that aim to reduce the level of discarding to zero may create greater costs than benefits. The actual optimal level of discarding will depend on several factors such as the catchability of the bycatch species, prices and costs, as well as the interactions between fisheries. Consequently, the optimal level of discarding will vary from fishery to fishery. However, if externalities are created in the fishery by discarding, the optimal level of discarding will be less than the natural level of discarding.

4.3 Estimation of the optimal level of discarding

In Chapter 3, the equilibrium level of catch and bycatch in an unregulated fishery was shown to be a function of the price of each species, the cost of harvesting and the biological characteristic of the fish species. A bycatch species could be driven to extinction if its rate of growth and its maximum potential stock size were low. A bycatch species did not influence the harvesting decision if its price was zero, but could affect the equilibrium level of effort if it had a non-zero price.

In this section, the analysis of the previous chapter will be extended to look at optimal harvesting rates and the optimal level of discards for three types of fisheries. The first fishery is one in which the bycatch species has no value. The level of discards under open access and the optimal level of discards assuming that discarding creates no externalities will be estimated. The effect of discarding related externalities on the optimal rate of discarding will also be examined. The second type of fishery is where the bycatch is the target species of a second fishery, but has no commercial value in the first fishery. The unregulated and optimal level of discarding will be also examined for this type of fishery. The third type of fishery is one in which the harvest of juvenile fish create externalities within the fishery. The effect of these externalities on the use of selective gear will be examined.

4.3.1 Two species fishery with non-commercial bycatch

For the purposes of estimating the unregulated level of discards and the optimal level of discards under the first two scenarios, the two species fishery example used in the previous chapter will be used again. In the previous chapter, the equilibrium levels of each stock in the two species fishery under conditions of free and open access were estimated. These were given by

$$(4.5) \qquad B_1 = \frac{k_2(\frac{r_1q_2}{r_2q_1} - 1) + \frac{c}{p_2q_2}}{\frac{p_1q_1}{p_2q_2} + \frac{k_2r_1q_2}{k_1r_2q_1}} \quad \text{and} \quad B_2 = \frac{k_1(\frac{r_2q_1}{r_1q_2} - 1) + \frac{c}{p_1q_1}}{\frac{p_2q_2}{p_1q_1} + \frac{k_1r_2q_1}{k_2r_1q_2}}$$

where B_i is the biomass of species i, r_i is the instantaneous growth rate of species i, k_i is the environmental carrying capacity of species i, p_i is the price of species i, q_i is the catchability coefficient of species i and c is the average cost of fishing effort. Since there is a possibility that the price of either species may be zero, and price appears as a denominator, the equation 4.5 can be re-expressed as:

$$(4.6) \qquad B_1 = \frac{p_2q_2k_2(\frac{r_1q_2}{r_2q_1} - 1) + c}{p_1q_1 + \frac{k_2r_1q_2p_2q_2}{k_1r_2q_1}} \quad \text{and} \quad B_2 = \frac{p_1q_1k_1(\frac{r_2q_1}{r_1q_2} - 1) + c}{p_2q_2 + \frac{k_1r_2q_1p_1q_1}{k_2r_1q_2}}$$

The growth of each of these species was given by

$$(4.7) \qquad \frac{dB_1}{dt} = G_1(B_1) - q_1EB_1 \quad \text{and} \quad \frac{dB_2}{dt} = G_2(B_2) - q_2EB_2$$

where $G_i(B_i)$ is the surplus growth function for species i. This is the amount of growth in the stock over and above that required to maintain the stock at the same level of biomass. For the purposes of the example, assume that the surplus growth function is logistic. That is, growth of each species is given by

$$(4.8) \qquad G_i(B_i) = r_iB_i(1 - B_i/k_i)$$

In equilibrium, the catch is equal to the growth. Hence, the equilibrium catch of each species is given by

$$(4.9)\qquad C_1 = r_1\left[\frac{p_2q_2k_2(\frac{r_1q_2}{r_2q_1}-1)+c}{p_1q_1+\frac{k_2r_1q_2p_2q_2}{k_1r_2q_1}}\right]\left[1-\frac{p_2q_2k_2(\frac{r_1q_2}{r_2q_1}-1)+c}{k_1\left[p_1q_1+\frac{k_2r_1q_2p_2q_2}{k_1r_2q_1}\right]}\right]$$

$$(4.10)\qquad C_2 = r_2\left[\frac{p_1q_1k_1(\frac{r_2q_1}{r_1q_2}-1)+c}{p_2q_2+\frac{k_1r_2q_1p_1q_1}{k_2r_1q_2}}\right]\left[1-\frac{p_1q_1k_1(\frac{r_2q_1}{r_1q_2}-1)+c}{k_2\left[p_2q_2+\frac{k_1r_2q_1p_1q_1}{k_2r_1q_2}\right]}\right]$$

From equations 4.9 and 4.10 it can be seen that the catch of each species is dependent upon a number of biological and economic parameters. Generalising from this is difficult as the level of bycatch and discarding will vary from fishery to fishery.

Assuming that the bycatch species has zero price and is discarded, the biomass and catch of the each species under free and open access can be given by

$$(4.11)\qquad B_1 = \frac{c}{p_1q_1} \quad \text{and} \quad C_1 = r_1\left[\frac{c}{p_1q_1}\right]\left[1-\frac{c}{k_1p_1q_1}\right]$$

$$(4.12)\qquad B_2 = k_2\frac{r_1q_2}{r_2q_1}\left[\frac{r_2q_1}{r_1q_2}-\frac{C_1p_1q_1}{r_1c}\right] \quad \text{and} \quad C_2 = k_2\left[r_2-\frac{C_1p_1q_2}{c}\right]\left[\frac{C_1p_1q_2}{r_2c}\right]$$

From equation 4.11, the open access equilibrium level of catch and biomass for the target species depends only on the price and biological characteristics of the target species as well as the cost of effort. For the bycatch species, the level of biomass and catch (and hence the potential level of discarding) can be expressed as a function of the catch and price of the target species as well as the characteristics of the bycatch species and the cost of harvesting.

The economically optimal level of discarding under such conditions is that which produces the maximum economic yield for the fishery as a whole. This is the yield that maximises the sustainable level of profits in the fishery. The maximum economic yield and the associated equilibrium level of stock can be found using constrained optimisation techniques. The objective of the optimisation is the maximisation of the net present value of profits, given by:

$$(4.13)\qquad PV = \int_0^\infty e^{-\delta t}\left[p_1q_1B_1 + p_2q_2B_2 - c\right]E\,dt$$

where δ is the discount rate. The function is maximised subject to the constraints

$$(4.14)\qquad 0 \le E \le E_{\max}\ ,$$

(4.15) $$\frac{dB_i}{dt} = G_i(B_i) - q_i E B_i \text{ , and}$$

(4.16) $$B_i \geq 0$$

The current value Hamiltonian[30] to this problem is given by

(4.17) $$\begin{aligned}\widetilde{H} &= p_1 q_1 B_1 E + p_2 q_2 B_2 E - cE + \lambda_1 (G_1(B_1) - q_1 B_1 E) \\ &+ \lambda_2 (G_2(B_2) - q_2 B_2 E) + \mu_1 B_1 + \mu_2 B_2 + \mu_3 E + \mu_4 (E_{\max} - E)\end{aligned}$$

where λ_i are the shadow prices associated with each growth constraint and μ_j are the shadow values associated with the level of biomass and effort. Following Clark (1990) and Hoagland and Jin (1997), it is reasonable to assume an interior solution such that the shadow values μ_j are all equal to zero. Given this assumption, the first order conditions for profit maximisation include

(4.18) $$\frac{\partial \widetilde{H}}{\partial E} = p_1 q_1 B_1 + p_2 q_2 B_2 - c - \lambda_1 q_1 B_1 - \lambda_2 q_2 B_2 \geq 0$$

(4.19) $$\frac{d\lambda_1}{dt} = \delta\lambda_1 - \frac{\partial \widetilde{H}}{\partial B_1} = \delta\lambda_1 - p_1 q_1 E - \lambda_1 (\frac{\partial G_1}{\partial B_1} - q_1 E) \geq 0$$

(4.20) $$\frac{d\lambda_2}{dt} = \delta\lambda_2 - \frac{\partial \widetilde{H}}{\partial B_2} = \delta\lambda_2 - p_2 q_2 E - \lambda_2 (\frac{\partial G_2}{\partial B_2} - q_2 E) \geq 0$$

The values of the shadow prices can be estimated from equation 4.19 and 4.20, assuming that they are non-zero, giving

(4.21) $$\lambda_1 = \frac{p_1 q_1 E}{\delta - \partial G_1 / \partial B_1 + q_1 E}$$

(4.22) $$\lambda_2 = \frac{p_2 q_2 E}{\delta - \partial G_2 / \partial B_2 + q_2 E}$$

Substituting these back into equation 4.18 gives the condition

(4.23) $$p_1 q_1 B_1 (1 - \frac{q_1 E}{\delta - \partial G_1 / \partial B_1 + q_1 E}) + p_2 q_2 B_2 (1 - \frac{q_2 E}{\delta - \partial G_2 / \partial B_2 + q_2 E}) = c$$

Assuming again a logistic surplus production (growth) function, equation 4.23 can be expressed as

---

[30] The current value Hamiltonian is similar in appearance to the Lagrangian function used in Chapter 3 for finding the optimal solution on a trip by trip basis. The current value Hamiltonian, however, is used for estimating an optimal solution over time, and forms the basis of optimal control theory. For further details, see Clark (1990).

$$(4.24)\, c = p_1 q_1 B_1 (1 - \frac{q_1 E}{\delta - r_1 + 2rB_1/k_1 + q_1 E}) + p_2 q_2 B_2 (1 - \frac{q_2 E}{\delta - r_2 + 2rB_2/k_2 + q_2 E})$$

In equilibrium, the catch is equal to the surplus production (growth) of each species. *Catch is also given by the expression $C=qEB$.* Given this, the equilibrium level of effort for a given biomass is given by

$$(4.25) \qquad E = \frac{r_1}{q_1}(1 - \frac{B_1}{k_1}) = \frac{r_2}{q_2}(1 - \frac{B_2}{k_2})$$

Substituting these expressions for effort into equation 4.25 results in the condition

$$(4.26) \qquad c = p_1 q_1 B_1 \left(1 - \frac{r_1(1 - B_1/k_1)}{\delta + r_1 B_1/k_1}\right) + p_2 q_2 B_2 \left(1 - \frac{r_2(1 - B_2/k_2)}{\delta + r_2 B_2/k_2}\right)$$

Solving this equation is extremely difficult (Clark 1990), and there exists the possibility of multiple optima and sub-optimal equilibrium solutions (Hoagland and Jin 1997). In the case where the bycatch species has a zero price, however, the solution is the same as that for a single species fishery, namely

$$(4.27) \qquad B = \frac{k}{4}\left\{\left[1 + \frac{c}{pkq} - \frac{\delta}{r}\right] + \sqrt{\left[1 + \frac{c}{pkq} - \frac{\delta}{r}\right]^2 + \frac{8c\delta}{rpkq}}\right\}$$

Where the second species has a passive use value, the price of the second species can be replaced by the damage function created by its discarding. This may vary with the level of discards (as in the analysis of the previous section). Assuming (for the purposes of simplicity) that the marginal damage is constant, the optimal set of stocks in the presence of discarding externalities can be given by

$$(4.28) \qquad c = p_1 q_1 B_1 \left(1 - \frac{r_1(1 - B_1/k_1)}{\delta + r_1 B_1/k_1}\right) - dq_2 B_2 \left(1 - \frac{r_2(1 - B_2/k_2)}{\delta + r_2 B_2/k_2}\right)$$

where d is the constant marginal damage per unit of discards of the second species. Again, solving such an equation is difficult.

Example: The eastern tropical pacific tuna fishery.

Hoagland and Jin (1997) developed a model of the eastern tropical Pacific tuna fishery similar to that described above. The model was developed in order to assess the optimal level of dolphin bycatch and discards associated with tuna harvesting[31]. The key biological and economic parameters estimated by Hoagland and Jin (1997) are presented

---

[31] Hoagland and Jin (1997) also considered the possibility of biological interactions between the species. For the purposes of this example, however, it is assumed that there is no biological interaction between the tuna and dolphin.

in Table 4.1. From the parameters in Table 4.1, the level of catch of each species under free and open access and the optimal levels can be estimated.

Table 4.1 Biological and economic parameters for eastern tropical Pacific tuna fishery

parameter		Tuna	Dolphin
r	instantaneous growth rate	1.911	$4.5\text{x}10^{-2}$
k	carrying capacity (kt)	644.085	660.018
q	catchability	$3.9\text{x}10^{-5}$	$1\text{x}10^{-6}$
p	price ($/t)	860	0
c	cost ($'000/day)	4.362	
δ	discount rate	0	

Source: Hoagland and Jin (1997)

The catch and bycatch of each species under free and open access can be estimated using equations 4.11 and 4.12. Under conditions of open access, the equilibrium level of tuna catch is estimated to be about 198.3 tonnes a year, the result of about 39,000 days of effort (Table 4.2). Associated with this catch is about 3.4 tonnes of dolphins. As the dolphin catch has no value, this is assumed to be discarded.

Table 4.2 Equilibrium catch, biomass and effort

parameter	units	Open access		Optimal catch (no damage)	
		Tuna	Dolphin	Tuna	Dolphin
Catch	(t)	198.3	3.4	295.2	7.3
Biomass	(kt)	130.0	86.4	387.1	373.2
Effort	days	39106	39106	19553	19553
Profit	US$m	0		168.6	

The optimal level of catch and discarding assuming zero marginal damage can be estimated from equation 4.27. From this, the optimal level of effort was estimated to be about 19,550 days resulting in 295 tonnes of tuna and 7.3 tonnes of dolphins. Hence, a profit maximising level of effort may result in an increase in the level of dolphin bycatch and discarding in absolute terms. However, as the dolphin stock size would also be greater at the maximum economic yield of tuna, discards of dolphins as a proportion of the dolphin stock size is substantially lower than under free and open access.

While a passive use value for dolphins has not been estimated, Hoagland and Jin (1997) assume that such a value would exist. The effects of such values on the optimal bycatch and discarding of tuna can be estimated using equation 4.28 and assuming a range of values. As mentioned before, solving this equation algebraically is not straightforward, but the solution to a numerical problem can be estimated using the 'Solver' facility in Excel (or similar features of other spreadsheet packages).

The results of this are summarised in Figure 4.4. From this figure, the optimal catch of both tuna and dolphins decrease as the passive use value of dolphins increases.

However, as the dolphin catch is small relative to the tuna catch, the passive use value needs to be substantial before any large reduction in dolphin catch is optimal.

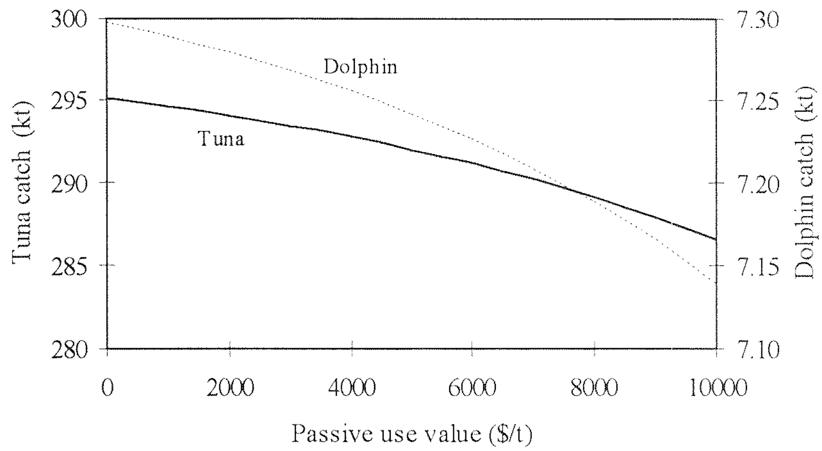


Figure 4.4 Optimal catch of tuna and dolphins with varying passive use value

Hoagland and Jin (1997) examined higher levels of passive use value than displayed in Figure 4.4. They found that the optimal bycatch of dolphins did not decrease substantially until the passive use value exceeded about 20 times the value of the target species.

While the results of this analysis are specific to the fishery modelled, there are some interesting features that may be applicable to other fisheries. First, the optimal level of discarding in this case is greater than the level that would occur under open access. This higher rate of discarding, however, is associated with much larger stocks of the bycatch species than under open access. From a conservation perspective, this higher level of discarding may be more acceptable than the lower level under open access. A second interesting point from this example is that if the catch of the bycatch species is small relative to the target species, then the damage associated with discarding the species needs to be high relative to the target species in order for the optimal level of discarding to be lower than if the damage was ignored.

4.3.2 Two fisheries with different target species

The second type of externality is the cost imposed on a second fishery by discarding bycatch species in one fishery which are the main target species in the second fishery. Several examples of such a problem have already been given above and also in Chapter 2.

The total profits from both fisheries can be expressed as

$$\pi = p_{1,1}q_{1,1}E_1B_1 + p_{2,1}q_{2,1}E_1B_2 + p_{1,2}q_{1,2}E_2B_1 + p_{2,2}q_{2,2}E_2B_2 - c_1E_1 + c_2E_2 \quad (4.28)$$

where $q_{i,j}$ is the catchability coefficient of species i in fishery j, B_i is the biomass of species i, $p_{i,j}$ is the price of species i received in fishery j, c_j is the cost per unit of effort of fishing in fishery j and E_j is the level of effort in fishery j.

The price of the species may vary between fisheries for a number of reasons. First, landing the bycatch species may be illegal if each fishery is subject to a fishery-specific quota control. For example, boats in fishery 1 may not hold quota for species 2, while boats in fishery 2 may not hold species for fishery 1. In this case, the fisher has no option but to discard the non-targeted catch. The price may also vary by gear type. Trawl gear targeting fish may also catch shellfish that gets damaged and is consequently unmarketable. These shellfish may be the target species of a pot fishery in the same area. For the purposes of simplification, the analysis will assume that the price received for the bycatch species in each fishery is zero.

The change in biomass of each species over time will be affected by both the catch in the main fishery and the bycatch in the secondary fishery. The growth of each species can be given by

$$(4.29) \quad \frac{dB_1}{dt} = G_1(B_1) - q_{1,1}E_1B_1 - q_{1,2}E_2B_1$$

$$(4.30) \quad \frac{dB_2}{dt} = G_2(B_2) - q_{2,1}E_1B_2 - q_{2,2}E_2B_2$$

In the absence of regulation, each fishery would operate independently so that all economic profits would be dissipated. Equilibrium would be achieved when

$$(4.31) \quad p_{1,1}q_{1,1}E_1B_1 + p_{2,2}q_{2,2}E_2B_2 = c_1E_1 + c_2E_2$$

and, assuming logistic growth,

$$(4.32) \quad r_1B_1(1 - B_1/k_1) = q_{1,1}E_1B_1 + q_{1,2}E_2B_1$$

$$(4.33) \quad r_2B_2(1 - B_2/k_2) = q_{2,1}E_1B_2 - q_{2,2}E_2B_2$$

From equations 4.32 and 4.33,

$$(4.34) \quad B_1 = k_1\left(1 - \frac{q_{1,1}E_1 + q_{1,2}E_2}{r_1}\right)$$

$$(4.35) \quad B_2 = k_2\left(1 - \frac{q_{2,1}E_1 + q_{2,2}E_2}{r_2}\right)$$

From equation 4.31

$$(4.36) \quad E_1(p_{1,1}q_{1,1}B_1 - c_1) + E_2(p_{2,2}q_{2,2}B_2 - c_2) = 0$$

As both E_1 and E_2 are greater than zero, and both fisheries are operating in the open access equilibrium, then

$$(4.37) \quad B_1 = \frac{c_1}{p_{1,1}q_{1,1}} \text{ and } B_2 = \frac{c_2}{p_{2,2}q_{2,2}}$$

Substituting the values for B_1 and B_2 from equation 4.37 into equations 4.34 and 4.35 gives

$$(4.38) \quad E_1 = \frac{r_1}{q_{1,1}}(1 - \frac{c_1}{k_1 p_{1,1} q_{1,1}}) - \frac{q_{1,2}}{q_{1,1}} E_2$$

$$(4.39) \quad E_2 = \frac{r_2}{q_{2,2}}(1 - \frac{c_2}{k_2 p_{2,2} q_{2,2}}) - \frac{q_{2,1}}{q_{2,2}} E_1$$

Solving equations 4.38 and 4.39 simultaneously results in expressions for E_1 and E_2, given by

$$(4.40) \quad E_1 = \frac{\frac{r_1}{q_{1,1}}(1 - \frac{c_1}{k_1 p_{1,1} q_{1,1}}) - \frac{q_{1,2}}{q_{1,1}} \frac{r_2}{q_{2,2}}(1 - \frac{c_2}{k_2 p_{2,2} q_{2,2}})}{(1 - \frac{q_{1,2}}{q_{1,1}} \frac{q_{2,1}}{q_{2,2}})}$$

$$(4.41) \quad E_2 = \frac{\frac{r_2}{q_{2,2}}(1 - \frac{c_2}{k_2 p_{2,2} q_{2,2}}) - \frac{q_{2,1}}{q_{2,2}} \frac{r_1}{q_{1,1}}(1 - \frac{c_1}{k_1 p_{1,1} q_{1,1}})}{(1 - \frac{q_{2,1}}{q_{2,2}} \frac{q_{1,2}}{q_{1,1}})}$$

Hence, the open access equilibrium level of effort in each fishery is a function of the prices in both fisheries, the target and bycatch catchability coefficients in both fisheries, the instantaneous growth rate in both fisheries and the cost of fishing.

Provided the fisheries can be effectively managed, the optimal level of biomass, catch and effort in each fishery can be estimated as a constrained optimisation problem as in the case of the single two species fishery above. The objective function is again the maximisation of present value of the discounted profits over time, given by

$$(4.42) \quad PV = \int_0^\infty e^{-\delta t}\big[p_{1,1}q_{1,1}E_1B_1 + p_{2,1}q_{2,1}E_1B_2 + p_{1,2}q_{1,2}E_2B_1 + p_{2,2}q_{2,2}E_2B_2 \\ -c_1E_1 - c_2E_2\big]$$

subject to the constraints

$$(4.43) \quad \frac{dB_1}{dt} = G_1(B_1) - q_{1,1}E_1B_1 - q_{1,2}E_2B_1$$

$$(4.44)\quad \frac{dB_2}{dt} = G_2(B_2) - q_{2,1}E_1B_2 - q_{2,2}E_2B_2$$

$$(4.45)\quad 0 \le E_1 \le E_{1,\max},\ 0 \le E_2 \le E_{2,\max}$$

$$(4.46)\quad B_1 \ge 0,\ B_2 \ge 0$$

The current value Hamiltonian to this problem is given by

$$(4.47)\quad \begin{aligned} \widetilde{H} &= p_{1,1}q_{1,1}B_1E_1 + p_{2,1}q_{2,1}B_2E_1 + p_{1,2}q_{1,2}B_1E_2 + p_{2,2}q_{2,2}B_2E_2 - c_1E_1 - c_2E_2 \\ &+\lambda_1(G_1(B_1) - q_{1,1}B_1E_1 - q_{1,2}B_1E_2) + \lambda_2(G_2(B_2) - q_{2,1}B_2E_1 - q_{2,2}B_2E_2) \\ &+\mu_1B_1 + \mu_2B_2 + \mu_3E_1 + \mu_4(E_{1,\max} - E_1) + \mu_5E_2 + \mu_6(E_{2,\max} - E_2) \end{aligned}$$

If we assume an interior solution as in the previous analysis, such that $\mu_i = 0$, the necessary conditions for profit maximisation are given by

$$(4.48)\quad \frac{\partial \widetilde{H}}{\partial E_1} = p_{1,1}q_{11,}B_1 + p_{2,1}q_{2,1}B_2 - c_1 - \lambda_1 q_{1,1}B_1 - \lambda_2 q_{2,1}B_2 \ge 0$$

$$(4.49)\quad \frac{\partial \widetilde{H}}{\partial E_2} = p_{1,2}q_{1,2}B_1 + p_{2,2}q_{22,}B_2 - c_2 - \lambda_1 q_{1,2}B_1 - \lambda_2 q_{2,2}B_2 \ge 0$$

$$(4.50)\quad \begin{aligned} \frac{d\lambda_1}{dt} = \delta\lambda_1 - \frac{\partial \widetilde{H}}{\partial B_1} &= \delta\lambda_1 - p_{1,1}q_{1,1}E_1 - p_{1,2}q_{1,2}E_2 \\ &- \lambda_1\left(\frac{\partial G_1}{\partial B_1} - q_{1,1}E_1 - q_{1,2}E_2\right) \ge 0 \end{aligned}$$

$$(4.51)\quad \begin{aligned} \frac{d\lambda_2}{dt} = \delta\lambda_2 - \frac{\partial \widetilde{H}}{\partial B_2} &= \delta\lambda_2 - p_{2,1}q_{2,1}E_1 - p_{2,2}q_{2,2}E_2 \\ &- \lambda_2\left(\frac{\partial G_2}{\partial B_2} - q_{2,1}E_1 - q_{2,2}E_2\right) \ge 0 \end{aligned}$$

The values of the shadow prices can be estimated from equation 4.50 and 4.51, assuming that they are non-zero, giving

$$(4.52)\quad \lambda_1 = \frac{p_{1,1}q_{1,1}E_1 + p_{1,2}q_{1,2}E_2}{\delta - \partial G_1/\partial B_1 + q_{1,1}E_1 + q_{1,2}E_2}$$

$$(4.53)\quad \lambda_2 = \frac{p_{2,1}q_{2,1}E_1 + p_{2,2}q_{2,2}E_2}{\delta - \partial G_2/\partial B_2 + q_{2,1}E_1 + q_{2,2}E_2}$$

Following the same procedure as in the previous section, the expressions for λ_1 and λ_2 can be substituted back into equations 4.48 and 4.49. Assuming also a logistic growth function, such that $G_i(B_i) = r_iB_i(1-B_i/k_i)$, the conditions can be re-specified as

$$c_1 = p_{1,1}q_{11,}B_1 + p_{2,1}q_{2,1}B_2 - q_{1,1}B_1 \frac{p_{1,1}q_{1,1}E_1 + p_{1,2}q_{1,2}E_2}{\delta - r_1 + 2B_1/k_1 + q_{1,1}E_1 + q_{1,2}E_2}$$

(4.54)

$$-q_{2,1}B_2 \frac{p_{2,1}q_{2,1}E_1 + p_{2,2}q_{2,2}E_2}{\delta - r_2 + 2B_2/k_2 + q_{2,1}E_1 + q_{2,2}E_2}$$

$$c_2 = p_{1,2}q_{1,2}B_1 + p_{2,2}q_{2,2}B_2 - q_{1,2}B_1 \frac{p_{1,1}q_{1,1}E_1 + p_{1,2}q_{1,2}E_2}{\delta - r_1 + 2B_1/k_1 + q_{1,1}E_1 + q_{1,2}E_2}$$

(4.55)

$$-q_{2,2}B_2 \frac{p_{2,1}q_{2,1}E_1 + p_{2,2}q_{2,2}E_2}{\delta - r_2 + 2B_2/k_2 + q_{2,1}E_1 + q_{2,2}E_2}$$

When both fisheries are in equilibrium, the level of effort in each fishery is given by

(4.56) $$E_1 = \frac{G_1(B_1) - q_{1,2}B_1E_2}{q_{1,1}B_1} \text{ and } E_2 = \frac{G_2(B_2) - q_{2,1}B_2E_1}{q_{2,2}B_2}$$

Again assuming logistic growth, the expressions in 4.56 can be re-expressed as

(4.57) $$E_1 = \frac{q_{2,2}r_1(1 - B_1/k_1) - q_{1,2}r_2(1 - B_2/k_2)}{(q_{1,1}q_{22} - q_{1,2}q_{2,1})}$$

(4.58) $$E_2 = \frac{q_{1,1}r_2(1 - B_2/k_2) - q_{2,1}r_1(1 - B_1/k_1)}{(q_{1,1}q_{2,2} - q_{2,1}q_{1,2})}$$

As there are four unknowns (B_1, B_2, E_1 and E_2) and four equations (4.54, 4.55, 4.57 and 4.58), a solution to this problem is feasible. However solving these equations algebraically is extremely difficult. The equations can be solved numerically, however, using a spreadsheet solver facility as in the previous section. The optimal level of discarding in a two fishery problem will therefore be examined through the use of an example.

Example: Northwest Atlantic cod and haddock fisheries

Androkovich and Stollery (1992) developed a model of the Northwest Atlantic cod and haddock fisheries similar to that described above. In their model, cod was caught as bycatch by fishers targeting haddock while haddock was caught as bycatch of fishers targeting cod. The analysis of Androkovich and Stollery (1992) differ from that described above, however, in that both catch and bycatch were landed and sold. In this example, it will be assumed (for the purposes of demonstration) that the bycatch will be discarded. Androkovich and Stollery (1992) also used a semi-logarithmic growth function in their model whereas a logistic growth function is utilised in this example. As the growth function and the assumptions about bycatch differ in this example, the results are not comparable to those of Androkovich and Stollery (1992).

The key parameters for estimating the optimal level of discarding are given in Table 4.3. The values of the instantaneous growth and carrying capacity parameters were estimated by solving equations 4.40 and 4.41 (using the solver in Excel) with given levels of effort in each target fishery[32].

Table 4.3 Key parameter relating to the Northwest Atlantic cod and haddock fisheries

Parameter	Cod fishery	Haddock fishery
Cod price	378.89	0
Haddock price	0	633.78
Cod catchability	2.54×10^{-6}	2.72×10^{-6}
Haddock catchability	9.30×10^{-7}	9.34×10^{-6}
Cost	359.51	86.22
Instantaneous growth	0.9982	0.4584
Carrying capacity	528161	102330

Source: Derived from Androkovich and Stollery (1992)

The open access level of catch, effort and discarding were estimated using equations 4.37 to 4.41 (Table 4.4). Effort in the cod fishery was estimated to be about 78,300 days while effort in the haddock fishery was estimated to be about 34,300 days. If fishers were unable to land their bycatch, then discards were estimated to be about 34,850 tonnes of cod and 1,060 tonnes of haddock.

Table 4.4 Open access and optimal levels of biomass, catch and effort

	Cod	Haddock
Open access		
• effort	78304	34299
• biomass	373563	14565
• catch	74299	4666
• bycatch/discards	34851	1061
Profit maximising		
• effort	53277	26012
• biomass	449908	41793
• catch	60883	10154
• bycatch/discards	31832	2071

Assuming both fisheries could be efficiently managed simultaneously, so that an overall profit maximising level of effort in each fishery could be maximised, then the optimal level of effort in both fisheries was expected to be lower and stocks of both species higher (Table 4.4). The optimal level of biomass and effort under such utopian conditions were estimated using equations 4.54 to 4.58. These equations take into account the effects of the bycatch mortality in a fishery on the other fishery, so an explicit

[32] The resultant parameters work well for the haddock fishery but not the cod fishery, with the resultant total level of effort in the cod fishery being less than that estimated by Androkovich and Stollery (1992) under open access conditions. However, for the purposes of the example the values will be accepted.

externality cost does not need to be included in the model as it was in the case of the passive use stock in the previous analysis.

The optimal level of cod discards was estimated to be only about 10 per cent lower than the open access level. The optimal level of haddock discards were almost double the open access level. As the biomass of both species under optimal management, however, were substantially higher than under open access, the level of discards were lower as a proportion of the total stock size.

This analysis does not take into account the costs of achieving the optimal management and level of discards. As pointed out in the previous sections, an alternative way of assessing the optimal level of discards is to consider the abatement costs. Given that regulating the fishery is not likely to be cost-less, the economically optimal level of discarding may fall somewhere between the open access and profit maximising level.

4.3.3 Discards of juvenile target species and gear selectivity

As seen in Chapter 3, individual fishers operating in an unregulated fishery have an incentive to discard fish only if the market price is less than the costs of landing and selling the fish. Provided that there are no inter-fishery interactions and that the discarded species do not have any non-market value (i.e. passive use value), such discarding may be considered socially optimal as the resources used in landing the fish would exceed its social value (as indicated by its market price). Where fishers can alter the selectivity of the gear, however, the fishers also have a choice of either discarding or avoiding these fish.

In section 3.2.1, the optimal gear selectivity for an individual fisher was determined by equating the marginal cost of avoiding that size class with the marginal benefits of not landing the fish. The marginal benefits of not landing the fish were assumed to also represent the marginal benefits of avoiding capturing the fish. The benefits of avoiding capturing the fish to the individual fisher, however, do not take into consideration the external costs that may result from the fishing activity. Discarding small or juvenile fish may result in a loss of future production in the fishery as these fish could be caught and sold at a more valuable size at a later date. Further, if the fishery was overexploited, harvesting juvenile fish prevents the stock rebuilding. Hence future yields may be lower than if the juvenile fish were avoided.

By ignoring these costs, the private benefits of avoiding the juvenile fish is less than the social benefit. Consequently, individuals have an incentive to adopt less selective gear than is optimal from a social perspective. Anderson (1997) argues that if these costs are taken into account, fishers would most likely choose a different harvesting strategy - one that employs greater selectivity. Hence, while the use of the less selective gear may be optimal to an individual, such gear may not be socially optimal.

The estimation of the socially optimal level of selectivity is similar in respects to estimating the effects of ITQs on discarding and selectivity. In section 3.4.3, it was shown that the opportunity cost associated with landing fish under ITQs affected the optimal combination of discarding and selectivity. However, while the opportunity cost of the quota applies to landed fish only, the externality cost from catching juvenile fish applies to all fish caught. Discarding these fish does not reduce the externality as they are presumed dead.

The individual fisher's profit function incorporating the externality is given by

$$\begin{aligned}\pi(e,d,x,p) &= \sum_i \left[(p_i - CL_i - \Phi_i) C_i(e,x,i).(1-a_i) - d_i(p_i - CL_i) \right] \\ &\quad - CE(e) - \sum_i CD_i(d_i) - \sum_i CS_i(a_i)\end{aligned} \tag{4.59}$$

where p_i is the price received for size class i, CL_i is the unit cost of landing[33] size class i, Φ_i is the value of the externality created by harvesting a fish of size i, $C_i(e,x,i)$ is the total catch of grade i, $CE(e)$ is the cost of effort, taken as a function of the level of effort, e, and $CD_i(d_i)$ is the discard cost function. Associated with the gear is a selectivity cost function, $CS_i(a_i)$, which is a function of the selectivity parameter a_i.

The externality cost will vary by size class. As a smaller proportion of the smallest size class will survive to maturity than larger size classes, the external cost produced by capturing one fish of the smallest size class will be less than the cost of capturing a fish in a higher size class. The externality will also vary depending on the state of the stock. If the resource is overexploited, the externality will be greater than if the stock is at its optimal size and structure.

Differentiating this profit function with respect to effort, discards and selectivity results in the necessary first order conditions for profit maximisation by the fisher:

$$\sum_i (p_i - CL_i - \Phi)\left[C_i'(e,x,i).(1-a_i)\right] = CE'(e) \tag{4.60}$$

$$-\left[p_i - CL_i\right] \le CD_i'(d_i) \tag{4.61}$$

$$-\left[p_i - CL_i - \Phi\right] C_i(e,x,i) \le CS_i'(a_i) \tag{4.62}$$

From the first condition, a profit maximising producer will continue to apply effort to the fishery until the marginal benefit of fishing (the revenue from catching the marginal fish less the cost of landing the marginal fish and the externality created) is equal to the marginal cost of the additional unit of effort evaluated at the total effort level, e, (i.e. $CE'(e)$). Consequently, if the externalities were explicitly incorporated into the decision process, the profit maximising fisher would fish less than when these externalities are not considered.

---

[33] In the earlier analysis this was assumed to vary with the level of landings. For simplicity, it will be assumed to be a constant unit cost.

The second condition is a restatement of the previous condition in equation 3.18. A net cost must be incurred by landing the fish (i.e. the landing costs exceed the price received) and this must be greater than the cost of discarding before discarding is an optimal option. This does not differ from the optimal discarding rule in an unregulated fishery as the discarding itself does not create any additional costs.

The final condition indicates that in order to employ more selective gear rather than discard, the net benefits received from catching the size class i (this is the net price including the externality times the quantity caught, assuming no discards) must be both negative and less than the marginal cost associated with achieving that level of selectivity.

This can be demonstrated graphically, using a similar approach to that used in sections 3.2.1 and section 3.4.3. In Figure 4.5, the marginal cost of discarding and selectivity intersect the private benefits of not catching the fish (the net cost of landing the fish) at d and a respectively. From this, the optimal selectivity for the individual fisher will be a, and the proportion discarded (after selectivity) will be d. Hence, the quantity of discards of grade i would be $C_i(e,x,i).(1-a).d$ (Arnason 1995).

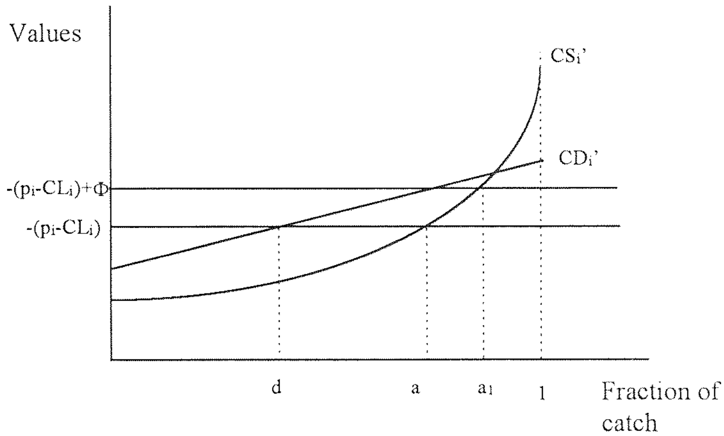


Figure 4.5 Optimal gear selectivity
Source: Based on Arnason (1995)

The addition of the externality that can be realised by avoiding capturing the fish (Φ) shifts the benefit curve upwards. This does not affect the optimal benefit of discarding, which remains at d. it does, however, affect the optimal selectivity, which increases to a_1. Hence the new quantity of discards would be $C_i(e,x,i).(1-a_1).d$. As a_1 is greater than a, less smaller fish would be caught with the more selective gear.

As the externality is not considered in the production process, less selective gear is used than is optimal. While this doesn't affect the incentives to discard, as a greater proportion of smaller fish are caught overall discard levels are higher than they should be from a social perspective.

4.4 Chapter summary

Fishing creates external costs that are not considered by individual fishers when forming their own production decisions. These externalities may take the form of reduced future yields in their own fishery from over-harvesting in general, reduced yields in other fisheries that target the bycatch species, or the loss of social benefits associated with bycatch that has no commercial value but may have a passive use value.

The theory underlying the optimal level of discarding is similar to that underlying the optimal level of pollution. The optimal level of discarding occurs when the marginal benefits from discarding equal the marginal costs. In the short term, the optimal level of discards is generally less than the unregulated level of discards. In the long term, however, the optimal level of discards may be greater that the unregulated level in terms of total volume. However, where this occurs the higher level of discarding is associated with higher stock levels of the discarded species. As a proportion of the total stocks, the long run level of bycatch and discarding is generally lower than in the absence of regulation.

An alternative way of determining the optimal level of discarding is to examine the costs associated with discard reduction. Reducing the level of discards imposes costs on fishers in terms of reduced production or increased harvesting costs. It also may require greater monitoring costs. The criteria for the optimal level of discarding is that the marginal cost of discard reduction is equal to the marginal damage created by the discarding.

Optimal discard rates can be estimated for individual fisheries using constrained optimisation techniques. The results cannot be generalised to all fisheries as they rely on the relationships between the parameters, particularly the catchability coefficients and the relative prices of the species. A set of necessary conditions for optimal discarding were established. These can be solved numerically for individual fisheries using solver facilities common to most modern spreadsheet packages.

5. Management measures to reduce discarding

The analysis of optimal discarding in the previous chapter was largely predicated on the assumption that fishers will not take into account the externalities created by their activity. Hence the level of fishing activity may be greater than that which produces the optimal level of catch and discarding. In the short run, discarding is likely to be greater than the socially optimal level in the absence of efficient regulation, although in the long run the optimal level of discarding may be higher than that of the unregulated fishery.

In Chapter 3, it was shown that management can change the incentives faced by fishers. Some policies impose restrictions on the type of fishing gear used while others provide incentives to avoid capturing unwanted fish. Hence, the level of discarding can be affected by the management plan.

Policies aimed at reducing discarding may fall into two categories. The first main type of policies are those that attempt to prevent or reduce the capture of unwanted bycatch species in the first place. These largely take the form of technical measures. The second set of policies is aimed at reducing the level of discarding of the bycatch species once caught. These take the form of primarily administrative arrangement or the creation of economic incentives to alter discarding behaviour. The purpose in this chapter is to review the various management policies aimed at reducing bycatch and discarding in commercial fisheries.

5.1 Technical measures

The main cause of incidental catch in most fisheries is the non-selectiveness of the fishing gear and the variations in seasonal abundance of different species and size classes. An unfortunate feature of fisheries is that, in the absence of effective management, less selective gear is often favoured over more selective gear as a greater short run yield is achieved per unit of effort. In the long run, however, less selective gear can lead to lower yields and profitability than the more selective gear. For example, in Kerala's fisheries, trawlers have replaced the traditional canoe based encircling nets used by the local fishers. While the quantity of bycatch in the fishery has significantly increased, the total quantity of shrimp currently harvested by some 5000 trawlers is no larger than that harvested by the canoes in the 1960s (Willmann, R., FAO, personal communication, October 1997).

Regulating the type of gear used is one way of overcoming the propensity for more selective gear to be displaced by less selective gear. Improving the selectivity of gear and altering the time and area fished is seen as a way of reducing incidental catch and hence discarding. A further technical measure is to reduce the amount of discarding through utilising a greater proportion of the catch. The effectiveness and economic consequences of these types of measure will be discussed below.

5.1.1 Gear selectivity

As discussed in the previous chapters, a major cause of incidental catch is the imperfect selectivity of fishing gear. With the generally low costs involved in discarding unwanted catch, there exist few economic incentives to adopt more selective gear in most fisheries. In the absence of regulations designed to reduce discarding, there is little demand for more selective gear, and hence there is little incentive to develop more selective gear by gear technologists.

The recent attempts to develop more selective gear that is also economically viable has been prompted by the increased regulation of gear in many fisheries, particularly shrimp fisheries. Research funding has also been increased in order to encourage the development of more selective gear. This has resulted in a number of gear modifications and designs that reduce the level of bycatch and hence the level of discarding. These different designs have had a varying impact on the level of discarding as well as having varying economic impacts on the fishers themselves and the fish population structure in the fishery.

Most attention has focused on the design of more selective trawl gear, either by changing the mesh of adding grids to divert unwanted catch. Developments in other gear types, however, have also been undertaken.

Mesh size regulations

As mentioned in Chapter 3, minimum mesh sizes have been adopted in many fisheries throughout the world as a means of reducing the bycatch of juvenile fish. For example, imposing a minimum mesh size has resulted in significant reductions in the catch of undersized fish in single species, directed fisheries such as the Alaska pollock fishery (Bublitz 1995).

Increasing the minimum mesh size, however, does not ensure that small fish are not caught. While mesh size can be varied to allow increased escapement of certain size class of fish, clogging of the mesh by gilled fish reduces the potential to escape. Hence, bycatch management based on cod-end mesh size may be ineffective in high volume fisheries (Suuronen 1995). In such fisheries the mesh can become blocked preventing the escapement of undersized fish.

Mesh size selectivity depends on cod-end dimensions (the ratio of length to diameter) and is affected by operational factors such as trawl towing speed, fish density and net fullness (Murawski 1990). The traditional diamond shaped mesh is likely to constrict under strain, reducing the size selectivity of the net. The use of square mesh as windows in the cod-end (or for the whole cod-end), and as windows in other parts of the net reduces the problem to an extent compared with nets made solely from the traditional diamond shaped mesh.

Broadhurst and Kennelly (1994) found that use of square mesh at the front of the cod-end allowed increased escapement of juvenile fish in the Hawkesbury River prawn trawl fishery. The number of juvenile fish caught were reduced by 46 per cent without a reduction in prawn catch. This was thought to be the result of the hydrodynamic pressure produced by the net and the behaviour of the species. The prawns disturbed by the net tended to swim backwards and downwards into the net while the free-swimming fish were able to exit out of the cod-end. In the Australian northern prawn fishery, trials with square mesh cod-ends have resulted in 33 per cent less fish bycatch compared with diamond mesh nets (Brewer and Eayrs 1994). Nets using square mesh have also been noted to reduce the catch of juvenile haddock by 30-40 per cent and whiting by 50 per cent in some European fisheries (Prado 1997).

Square mesh nets were also mandatory in the Canadian trawl fisheries for white fish prior to the cod moratorium. Despite the subsequent moratorium the use of the square mesh nets were considered successful in reducing the catch of smaller fish. The use of square mesh in Canadian shrimp fisheries, however, has proved less successful. While reducing the quantity of small shrimp caught, trials with square mesh resulted in a higher proportion of broken and damaged shrimp (Duthie 1997). Hence, the value of the retained catch was lower than when diamond mesh was used. The square mesh net was also thought to be more difficult to handle compared with the traditional diamond mesh (Duthie 1997).

The potential effect of the mesh size on the size distribution of the catch differs from species to species. For example, flatfish have a different body shape than roundfish. Consequently sole or plaice will go though mesh differently than cod or pollock. Hence the effectiveness of the regulation in reducing incidental catch decreases as the number of species in the fishery increases (Ueber 1990). With multispecies fisheries, there will be no single optimum mesh size (Hanna 1990).

Escaping through the mesh does not ensure that the animals survive. A proportion of smaller fish escaping from trawls through mesh die as a result of injuries received by passing through the mesh (Jacobsen *et al* 1992, Soldal 1993). As a consequence, mesh size regulations may be questionable as a conservation measure (Christensen 1995).

Christensen (1995) developed a bioeconomic model to estimate the potential benefits of increasing the mesh size of shrimp trawlers to allow juvenile shrimp to escape. He estimated that the benefits of the increase were highly sensitive to the survival rate of the escaping shrimp, with at least 50 per cent survival being necessary in order to produce a positive economic benefit.

As seen above, the selectivity characteristics of the mesh vary depending on the type of fishing activity being undertaken. Fishers can also circumvent the regulation relatively easy by further modifying the gear. Fishers have been known to employ a number of methods to reduce the size selectivity of the nets while still complying with the regulation.

For example, the use of double-layered cod-ends effectively reduces the mesh size, while tying loose knots allows the mesh to close under drag. Enforcement at sea is difficult. Surveillance can only take place while the net is out of the water, at which time the net meets the technical requirements of the regulation.

Bycatch reduction devices

A variety of devices have been developed in order to separate the catch before it enters the cod-end of the nets. These devices generally involve some form of separator panel or grid and an escape panel to allow unwanted animals to escape (Prado 1997). The devices separate fish of different sizes, allowing smaller animals to pass through the grid while deflecting the larger animals out of the net. For example, the Nordmøre grate (Figure 5.1), developed in the Nordmøre district of Norway (Isaksen 1997), has been used successfully in allowing fish to escape from shrimp nets by directing the larger sized fish up to an escape panel. Conversely, a variant of the grate can be used to reduce the level of small size fished in a number of finfish fisheries by directing the larger animals to the cod-end and allowing the smaller animals to pass though the grid and back out of the net.

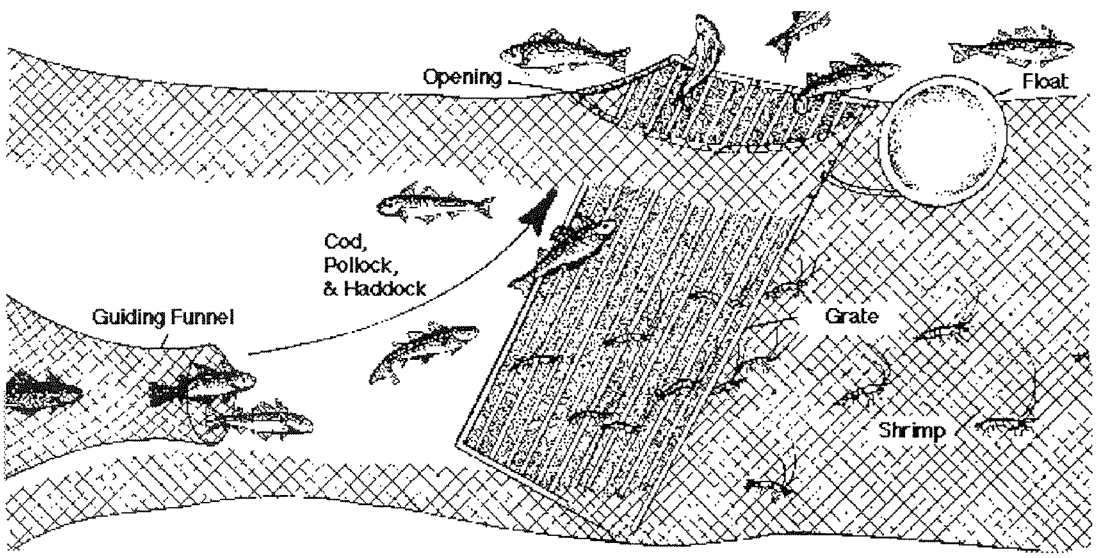


Figure 5.1 The Nordmøre grate
Source: Corey and Williams (1995)

Use of the Nordmøre grate is compulsory in both Russian and Norwegian shrimp fisheries (Isaksen 1997). A variant of the grate to separate out small fish in bottom trawls has also be trialed in Norway, and has been found to be more successful in separating juvenile and small fish than just relying on the normal size selectivity of diamond-mesh cod-ends (Isaksen 1997). The use of these grid systems are compulsory now for Russian and Norwegian bottom trawlers (Isaken 1997).

The Nordmøre grate is also required by regulation for Northern shrimp fishery in the Gulf of Maine shrimp fishery (Corey and Williams 1995). The grate allows shrimp to pass through the bars into the net's cod-end while deflecting the larger fish. The grate reportedly decreases the bycatch of fish without a significant reduction in shrimp catch (Corey and Williams 1995).

In eastern Canada, use of the Nordmøre grate has also reduced bycatch of fish in shrimp and silver hake trawl fisheries (Brander 1996, Duthie 1997). The use of such devices is mandatory in some fisheries for part of the season. However, the devices are often being used year round by fishers. Reasons for use outside the mandatory period include convenience (i.e. not having to remove and install the grid), to reduce the amount of bycatch and hence sorting time, and to protect against catches of large sharks and marine mammals which can damage the catch (Duthie 1997).

A variant of the grid system described above is the Turtle Excluder Device (TED). These are designed primarily to reduce the incidental bycatch of turtles in tropical shrimp fisheries. As with the Nordmøre grate, turtles entering the net are deflected out of the net through an escape hatch. The smaller shrimp pass through the grid and into the cod-end. Such devices are mandatory in the Gulf of Mexico shrimp fishery, with compliance estimated at 95 per cent (Jones 1997). The regulation was introduced following a threat to sue the National Marine Fisheries Service by the Centre for Environmental education for failing to enforce the Endangered Species Act (Murray, Bahen and Rulifson 1992).

The TED, however, was not particularly effective in reducing bycatch of other species unless the bar spacing of the grid was narrowed. This lead to a decrease in the catch of the shrimp, which were often larger than the bycatch fish species.

The economic consequences of introducing such gear varies from fishery to fishery. The reduced catch of unwanted species as a result of using such devices reduces the costs associated with sorting the catch. However, in most fisheries the devices have also resulted in a reduction in the targeted catch. This results in a decrease in income to the fisher. Further, in some fisheries the bycatch can form a valuable component of the fisher's revenue. Hence reducing the amount of bycatch can further decrease the income of the fisher.

In the Texas shrimp fishery (Gulf of Mexico), trials with a variety of TEDs suggest that catch rates of shrimp can be reduced by up to 10 per cent (Clark *et al* 1991). This result was not universal, however. The use of the one TED design increased shrimp catch in all trials (Clark *et al* 1991). Clark *et al* (1991) not surprisingly concluded that the economic impact of the TED at the individual boat level depends on whether the catch rate is decreased or increased as a result of the device.

Estimates of the economic effects of TED regulations at the fishery level have suggested that significant costs may be borne by fishers. The introduction of TEDs in the Gulf of Mexico shrimp fishery is estimated to cost the industry an average of US$1 million a year in lost production and increased harvesting costs (Griffin and Oliver 1991)[34]. Reducing the bar spacing in the grid to reduce the bycatch of fish would further increase these costs (McQuaid 1996). Hendrickson and Griffin (1993) estimated that introducing bycatch reduction devices into the fishery that will remove fish from the catch could cost the industry between an average of US$1.6 million and US$2.7 million a year in lost rents. The higher production costs were also seen to place the US shrimp producers at a competitive disadvantage with shrimp producers in other countries. Concern as to the additional costs being borne by US shrimp fishers lead to an embargo on shrimp from countries that did not adopt similar devices, unless they naturally did not have problems with incidental catch of turtles (Gutting 1997). This embargo helped support the price of shrimp above what it might otherwise have been, cushioning the loss to the fishers at the expense of the consumer.

Ward and Macinko (1993) suggest that any inefficiencies that might occur as a result of the use of bycatch reduction devices may have indirect beneficial effects on the level of bycatch as well as the direct effect. The increased costs of harvesting may result in a reduction in the level of effort and hence a reduction in the level of bycatch. However, they argue that there are more efficient methods of achieving the same result other than imposing inefficiencies on the fleet.

Not all fisheries experience such costs as a result of the use of bycatch reduction devices. As noted above, the more northern US shrimp fisheries, Canadian shrimp fisheries and the Norwegian fisheries have not experienced substantial declines in productivity. In some Canadian shrimp fisheries, preventing the capture of sharks and marine mammals resulted in less damage to the catch and greater average returns. Trials with the Nordmøre grate in Australian prawn fisheries also suggest that substantial reductions in fish bycatch can be achieved while maintaining prawn catches (Kennelly and Broadhurst 1995). Rulifson *et al* (1992) also found no significant reduction in catch for two of three bycatch reduction devices tested.

The costs (if any) imposed on fishers as a result of using these devices needs to be compared with the value of the externalities created through discarding. While the cost to Texas shrimp fishers noted above appears significant, this cost may be less than the externalities the fishery were creating prior to their use. Unfortunately, the nature of externalities is that the costs are often not readily observable, while the costs being borne by fishers are observable.

Economic studies to date have generally not taken into account the reduction in external costs as a result of the use of these devices. One such study suggested that such gains may not be significant. Ward (1994) developed a model involving two fisheries where the bycatch of one fishery was the target of the other. He concluded that the use of

[34] Based on the estimated net present value of rent losses over a ten year period.

bycatch reduction devices would not result in any conservation benefits in such a case as effort would increase in the second fishery. Without effective management, all rents in the second fishery would be dissipated as a result of the increased effort so that there would be no long term economic gain from the reallocation of the resource (Ward 1994). If effort could be effectively controlled, however, long term benefits may be realised. Hence, on their own, the use of bycatch reduction devices may not be able to produce long run economic benefits where the bycatch of one fishery is the target species of another fishery.

The use of such devices may have other economic and environmental impacts on the fishery. Where non-selective gear has been used for some time it is likely that the fishery ecosystem structure has changed, favouring those species that have been less vulnerable to incidental fishing pressure. Hence changing the selectivity of the gear may result in a further change in the species mix with unknown effects. For example, where the discarded species in a fishery interact with the target species population, reducing the level of discards may result in further costs to fishers. Simulation models of the US southeastern shrimp fishery suggests that increases in the population of fishfish as a result of bycatch reduction may lead to increased shrimp predation and a decline in the stock of as much as 10 per cent (Branstetter 1996).

Alternative trawl design

For a number of species bycatch can be reduced by using midwater or semi-pelagic trawls rather than the traditional bottom trawl. Trials using semi-pelagic trawls in the Australian northern fish trawl fishery found that catches of species that would normally be discarded could be reduced without loss of catch of the target species (Brewer *et al* 1996). While termed semi-pelagic, the most effective design had the footrope 'flying' between 0.4 and 0.5 metres off the bottom. This is achieved by a combination of headline floats and steel weights attached to the footrope, and the use of a special rigging (Brewer and Eayrs 1994).

The midwater trawl fishery for Alaskan pollock in the Bearing Sea has been described as one of the cleanest fisheries in the world in terms of bycatch (Pereyra 1995). However, the gear tends to catch smaller pollock than the demersal trawl. Hence there is a trade-off between catching less bycatch and catching larger fish (Pereyra 1995).

Reducing bycatch in non-trawl gear

The use of rigid grids in purse seine nets has also been successful in allowing increased escapement of small fish. Purse seine nets with rigid sorting grids have been used in mackerel and saithe fisheries by Norwegian purse seiners (Beltestad and Misund 1995).

Considerable reductions in dolphin bycatch in purse seine fisheries have been achieved through the use of the backdown procedure where the dolphins are allowed to escape before the net is hauled. Fishers have been encouraged to adopt this technique in order for their catch to be acceptable by processors wishing to use the 'dolphin-safe' marketing symbol. Fishers who choose not to use these procedure face only a limited range of outlets for their catch. A technical measures that have proved effective in reducing bycatch of dolphins by gillnets include pingers and other sonic scaring devices (Lien 1995, FAO 1997, Warren *et al* 1997). Setting the nets one metre below the surface has also proved effective in reducing the bycatch of dolphins in drift nets.

The use of excluder rings in crab pots has been shown to reduce the capture of undersized, soft or female snow crabs while not affecting the catch of legal sized male crabs (Chiasson *et al* 1993). These rings create an additional barrier to entry for smaller crabs but do not impede larger crabs. Similarly, increasing the height of the entrance of the pot has also proved successful in reducing catch of smaller crabs (Miller 1995).

The use of large mesh panels on one side of the square pot has also proved successful in allowing smaller crabs to escape in the Alaskan red king crab fishery (Stevens 1995). Similarly, escape rings in Dungeness crab pots have also been successful in allowing smaller crabs to escape (Stevens 1995). In the latter two examples, however, some loss of legal sized crabs were also experiences (5 per cent and 7 per cent respectively). Hence the potential benefits of the reduced bycatch need to be weighed against the potential reduction in revenue.

The use of pots and lines instead of trawl gear to target particular species may be an alternative method of reducing bycatch and discards. Both pots and lines have been used in the Bering Sea to harvest cod with substantially less bycatch of halibut than the trawl fishery (Wyman 1995). In 1991, 44 per cent of the total allowable catch for cod had been explicitly allocated to the use of fixed gear (both line and pots) to encourage fishers to use these gear types (Smith 1995b).

The economic viability of the use of static gear to a larger extent in this fishery has not been examined. In 1994 and 1995, about half the catch of cod in the Bearing Sea was taken by longline, but only about 5 per cent was taken by pots (Wyman 1995). The adoption of long line fishing by a large proportion of fishers suggest that this may be an economically viable harvesting strategy. However, the lack of adoption of pots suggest that they are not considered as efficient at catching the target species in the Bearing Sea as trawl gear.

Bans on certain gear types

In some cases, total bans on particular gear types can be implemented as a management plan. In 1980, the North Pacific Fisheries Management Council proposed that trawl gear be prohibited from harvesting cod in the Bearing Sea in favour of static gear (Smith 1995b). As outlined above, such a proposal was not implemented, but quota was removed from the trawl sector and given to the static gear sector in an attempt to reduce the total level of bycatch of halibut and other species.

The ban on use of driftnets in the high seas was a direct result of the desire to reduce bycatch, based on perceptions of waste, conservation and ethical issues (Alverson *et al* 1994). Gill nets are currently banned in Florida's inshore water as a result of the perceived impact the gear has on the fish stocks. While these have not been banned out of concern for discarding *per se*, the ban does demonstrate the willingness of fisheries managers to undertake severe measures to protect the resource.

The possible banning of the use of set bag nets in the Bay of Bengal has also caused considerable concern to the local fishing community. The small mesh gear is thought to catch juveniles of commercially important species (Clucas 1997a). While the banning of the gear may be seen as efficient in this case as it may be creating a significant externality problem, the lack of alternative income sources in the region creates a difficulty for managers implementing the ban.

5.1.2 Area and seasonal closures

Time and area closures can be effective in reducing the incidental catch of some bycatch species or the catch of juveniles of the target species. Seasonal closures prevent fishing during particular periods while area closures prevent fishing in particular areas. Often, the two types of closures are used in combination.

In the Australia northern prawn fishery, seasonal closures are used to prevent the capture of immature prawns. This is more for economic rather than biological reasons as a larger yield consisting of more valuable sized prawns can be achieved by delaying the opening of the season (Dann and Pascoe 1994). The closure is also thought to assist in reducing the potential for recruitment overfishing (Somers and Wang 1997). Without the imposition of the seasonal closure the fishers have an incentive to harvest the prawns at a smaller size, resulting in an overall lower level of profit in the fishery.

Seasonal closures are implemented in the Gulf of Mexico shrimp fishery for similar reasons as described above (Richards 1990, Turner 1990). However, seasonal and area closures have also been suggested as a means to reduce the bycatch of red snapper, Atlantic croaker and king mackerel in the fishery (Hendrickson and Griffin 1993). The effects on the level of bycatch and profits of closing the offshore component of the fishery at different times of the year were estimated using a bioeconomic model of the fishery. The results of the model suggest that such closures would be relatively ineffective in terms of bycatch reduction and considerably more costly to the industry that bycatch reduction devices (Hendrickson and Griffin 1993)

Seasonal and area closures, however, have proved more effective in other fisheries in reducing the level of discarding. In the Dungeness crab fishery on the US west coast, seasonal closures are used to protect the crabs during moulting (Richards 1990). Moulting crabs have soft shells and would be discarded if caught.

Closures of areas to trawling in the Eastern Bering Sea have been implemented in order to protect the stocks of red king crabs. While the total bycatch of the crabs by trawlers has not been high in proportion to the total trawl catch, the bycatch was a significant proportion of the crab stock and was thought to be having an adverse effect on the stock. The areas closed were those of greatest stock abundance. However, as the key breeding and spawning area is outside the closed area the effectiveness of the closure is uncertain (Armstrong *et al* 1993).

In addition to the above area closures, the Eastern Bering Sea trawl fishery is also subject to a series of prohibited species catch caps (PSCs). These are in place for halibut, red king crab and Tanner crab. When the aggregate catch by trawlers of any of these species exceeds the PSC the fishery is closed for the remainder of the season, even if the quotas for other species are unfilled. To reduce the potential cost of lost production, fishers have developed a voluntary system of moving area closures based on bycatch catch rates (Gauvin *et al* 1995). Areas that are identified as bycatch 'hot spots' are notified to the fishers who voluntarily avoid fishing in these areas. As a result the total bycatch is minimised with respect to the landed catch of the target species. While participation in the scheme is voluntary, participation rates appear high (Gauvin *et al* 1995).

Similar closures of 'sensitive areas' are undertaken in the Norwegian fisheries. Chartered commercial fishing vessels are used to provide information on catch rates in the various areas of the fisheries (Isaksen 1997). Unlike the voluntary closures of the Eastern Bering Sea, the Norwegian closures are imposed by fisheries managers and subject to surveillance and enforcement measures.

5.1.3 Increased bycatch utilisation

While not overcoming the problem of increased incidental mortality, the utilisation of bycatch overcomes the perceived waste associated with discarding. Policies encouraging the full utilisation of bycatch are in place in a number of countries. The major policy encouraging increased bycatch utilisation is the ban on discarding in place in several fisheries (e.g. Norwegian shrimp and fish fisheries, New Zealand fisheries for quota species and US North Pacific fisheries). Further details on these policies are given in the following sections.

Considerable attention has focused on utilising bycatch from tropical shrimp fisheries as these contribute the greatest levels of discards and are often found in regions where fish form a major part of the diet (Clucas 1997a). National and international agencies have spent considerable time and effort examining the possible utilisation of shrimp bycatch over the last two to three decades (Clucas 1997b). These include developing feed for aquacultural production, and the utilisation of the bycatch in products such as fish sauces and fish balls.

However, bycatch in many shrimp fisheries consists of small species with traditionally low commercial values. Also, many commercial shrimp vessels spend several days at sea each trip. Keeping bycatch fresh requires utilising the refrigeration space. As discussed in Chapter 3, a main reason that fish are discarded is that they either have no commercial value, or that their value is less than the opportunity cost of taking up limited hold space.

For example, Pender, Willing and Cann (1992) estimated that a large proportion of the bycatch of Australian north prawn boats was marketable yet only 5 per cent of it was being retained. The main problem with retaining the bycatch was the space it consumed in the freezers - space that could be otherwise utilised to store the more valuable prawn catch.

In Mozambique, this storage problem has been overcome for the shrimp fishery by the use of small artisanal boats to unload the lower valued bycatch at the end of each day (Jensen 1986, Clucas 1997b). These fish are then used for local consumption or dried for distribution along the coast.

Similar collections of bycatch from shrimp trawlers have been reported in India (Clucas 1997b), Nigeria (IFAD 1988) and Cuba (Joyce 1996). In Cuba, the bycatch is collected each day from the trawlers by packers who take it to the processing plants. The more valuable bycatch species (e.g. blue and stone crab) are processed for export while the less valuable species are reduced to meal (Joyce 1996).

In most fisheries, however, full utilisation may not be a desirable policy. As seen in Chapters 3 and 4, some level of discarding is optimal from a social perspective. Technological solutions to the problem of utilising the bycatch may not be sufficient (Clucas 1997b) if the resultant value of the product is less than the cost of landing it, including the opportunity cost of catch forgone as a result of retaining the bycatch.

5.2 Administrative measures

Administrative arrangements are in place in a number of fisheries in order to deal with unwanted bycatch. Most of these policies are in place in fisheries managed by ITQs and are an attempt to deal with some of the problems specific to this form of management, particularly over-quota catch. These policies include allowing quota to be traded, restrictions on the combination of quota holdings, permissible levels of quota overrun, informal quota trading arrangements and prohibition of discarding with un-penalised surrender of over-quota catch.

5.2.1 Quota trading

In ITQ fisheries, fishers are able to buy and/or lease quota in order to cover their over-quota catch, provided that the TAC for the species has not been filled (in which case there would be no quota available to buy or lease). Boyce (1997) demonstrates that a competitive ITQ management system is capable of producing the optimal level of catch in a fishery provided that a market exists for each quota.

Quota trading is the preferred option in any ITQ system for dealing with bycatch. However, the market for quota is generally not perfect. Buying and leasing quota involve transactions costs. A significant transactions cost in many ITQ fisheries is the costs involved in finding quota to buy. With a poorly developed quota market such costs can be high. In a well developed quota market, the search costs are reduced by the existence of quota brokers. However quota trading still incurs an additional cost in the form of the broker's fees.

Transactions costs can also occur if managers charge an administrative fee to allow a quota transfer. In a number of countries where cost recovery policies are in place, a fee is charged to cover the costs incurred by managers in allocating the quota to the new owner.

In some cases, the combined market price of the quota and the transactions costs may be greater than the benefits in acquiring the quota. As the TAC is approached, the lease price for quota is likely to increase as the amount available for leasing will be diminished. For higher cost producers (i.e. those further away from the market), the benefits of landing the over-quota fish once the lease cost and transactions costs have been taken into account may be negative. Hence these producers would not attempt to buy quota and would discard their over-quota catch.

Quota trading is not likely to counter highgrading of catch. Buying or leasing quota reduces the net price received from landing fish. From Chapter 3, this is likely to encourage highgrading, with only the most valuable grades landed. However, as the over-quota catch would have been discarded anyway, the level of discarding is no worse than if the fisher was not able to obtain quota.

Quota trading can also not take place if the TAC is filled. Incidental catch of a target species can still take place after the TAC has been reached. This may be as bycatch of other targeted species for which quota is still available. From Chapter 3, the effect of a filled TAC is similar to a trip limit in that the over-quota catch is discarded. Fishers still have an incentive to target other species even if they cannot land all of their catch.

For these reasons, other bycatch management policies are also required for ITQ fisheries in order to reduce the level of over-quota catch and discarding.

5.2.2 Fixed quota packages

A fixed quota package policy would require fishers to hold quota for the various species they are likely to catch in a fixed proportion. For example, if the catch/bycatch ratio of two species was expected to be 2:1, then the amount of quota held by the fisher for each species would also be required to be in the ratio of 2:1. Similarly, any purchase or sale of quota for a target species could only occur if corresponding amounts of bycatch species quota were also traded. The idea behind such a policy is that fishers would exhaust all quota simultaneously. Hence, there would be no further incentive to continue to fish and discard the over-quota catch.

The extent to which this approach will reduce discarding of bycatch depends first on how accurately managers can predict relative abundance of species which are caught together, and second on the extent to which these relationships are consistent across the fishery (Baulch and Pascoe 1992). In many fisheries the species abundance varies from year to year, within the year and also across the fishery. Determining a set of quotas that minimise over-quota catch of all species would be extremely difficult. Fishers will catch the various species in differing combinations depending on where and when they fish. If they exceed their individual quota on a species they will not be able to buy in additional units of quota for that species without also buying quota for the associated species. Hence the cost of purchasing quota to cover over-quota bycatch may be increased significantly.

Such a policy would also prevent fishers from changing their behaviour and consequently changing the species mix caught. Fishers are locked in to their previous fishing behaviour by the fixed quota mix (Baulch and Pascoe 1992).

Given these problems, a policy involved with fixed quota packages is not likely to provide any substantial benefits in terms of discard reduction.

5.2.3 Size specific quotas

A similar policy to that above is to have quota allocated to the various species in fixed grade proportions upon landing (Anderson 1994). For example, if a species had two grades that were generally caught in the proportion of 2:1, with the greater proportion being the larger (more valuable) size grade, then three units of quota can be deducted for every two units of the higher valued grade landed. Hence, the incentives to discard the low valued grades are reduced.

Anderson (1994) demonstrates that such a policy can have beneficial effects on the total level of highgrading in a fishery. However, setting a proper share will be difficult as the size composition will differ from fisher to fisher, area to area and season to season (Anderson 1994, Vestergaard 1996). Boats that catch more lower grade fish relative to the higher grade fish than the average would still be able to highgrade and increase their individual profits. They would reduce their total effort, however, compared with what they might have expended if they were able to highgrade without their quota being reduced. Hence, discarding would be lower than it might otherwise be. Boats that catch less low grade fish than the average would find that their effective total quota was lower, even if they landed all of the lower grade fish caught. The incentive for these boats would be to stop highgrading completely.

While the level of highgrading is likely to decrease under such a policy, the incidence of the restrictions is unequal across the fishery. Some fishers would incur a higher cost than others. Information on the amount of catch by size class would be necessary in order to calculate the appropriate deduction from the individual quota. Recording catches by size class would also add additional costs to fishers and fishery managers. For these reason, such a policy is not likely to be accepted readily by fishers and fishery managers.

5.2.4 Permissible quota over-runs

A permissible quota over-run policy allows fishers to exceed their quota holding in a given year in return for a reduction in their quota the following year. Such a policy is generally proposed as a device to compensate for difficulties in estimating TACs. Given these difficulties, there are likely to be times when the TAC of a bycatch species is lower than it should be given its stock abundance being higher than expected[35]. In such cases, the TAC for the bycatch species would be filled faster than expected and significant quota over-runs may be experienced as the fisher attempts to continue to fill his or her other quota.

By permitting the over-quota catch to be landed rather than discarded, the fishery managers have a better idea of the total fishing mortality so are likely to be able to produce better estimates of the TAC in the following year. However, once the permissible over-run has been reached, discarding will still continue if it is still profitable to land only the target species (Baulch and Pascoe 1992). Hence the additional knowledge is still not complete knowledge, and the benefits of the policy in terms of providing better information for assessing stock dynamics are limited.

Permissible quota over-runs is used as a bycatch management option in New Zealand (Wheeler, Bradford, Collins, Duncan, Wilson and Young 1992), and is also employed in the Australian south east fishery. In New Zealand, permissible quota over-runs are limited to 10 per cent of the original quota for all species.

5.2.5 Recording catch against another's quota

Another system used in New Zealand allows fishers to land species for which they do not hold quota and record it against the quota held by another fisher. This is effectively an informal quota leasing arrangement, as the catchers of the fish usually pay the holders of the quota for the use of their quota (Baulch and Pascoe 1992).

The need for such arrangements indicates an inadequacy in the formal quota trading system. With each quota lease, the management agency in New Zealand charge an administrative fee. This administration fee is avoided by the use of an informal lease.

---

[35] For this same reason, fishers often argue that quota not filled in a year due to unexpectedly low stock abundance be carried over to the next year. That is, the quota should be increased the following year if not filled. While fishery managers are sometimes willing to accept the over-run argument, the under-run argument is not in holding with the precautionary principle detailed in the UN Code of Conduct for Responsible Fishing.

Hence fishers prefer the use of informal leases since it results in a lower transactions cost to them. This system creates substantial administrative difficulties for management as records of the informal quota transfer are not explicitly created and managers have to reconcile the quota used by each fisher against the quota owned by them and other fishers. Hence the system may results in overall greater management cost than incurred under a formal quota leasing system. Improving the efficiency of the formal leasing system would result in the same benefits at a lower cost (Baulch and Pascoe 1992).

Such a system is also only effective as long as there remains unfilled quota. As with quota trading, the informal leasing arrangement could encourage highgrading as the net price received from landing the fish is reduced.

5.2.6 Compulsory landing of all catch

Unlike most countries which employ quota based management, Norway has imposed a system where all catch must be landed and discarding is explicitly forbidden (Olsen 1995, Isaksen 1997)[36]. All catch of quota species is then deducted from the quota. Individual fishers are responsible for their own catch and must ensure that they have sufficient quota to allow for any bycatch of quota species when targeting other quota species. Further, fishers are required to leave a fishing ground if they think that the catch may include some illegal bycatch. For non-trawl fishers, a bycatch limit is placed on cod over and above the individual quota holding (Olsen 1995).

This policy has had a number of effects on the Norwegian fisheries. In particular has been the strong incentive it has produced to develop and apply more selective gear such as the Nordmøre gate mentioned previously (Olsen 1995, Hall 1995b). The use of more selective gear and the use of seasonal closures were additional requirements imposed on fishers to complement the discard ban (Isaksen 1997).

In New Zealand also, legal sized fish subject to the quota management system cannot be discarded unless an observer is present who then ensures that the catch is recorded against the fisher's quota (Baulch and Pascoe 1992). The operator is allowed a period after landing the catch in which to acquire quota. If this is not done, the catch is either surrendered or some other mechanism (such as the deemed value described below) must be used or the catch surrendered.

In the US, the North Pacific Fishery Management Council has adopted full retention requirements (i.e. no discarding) for walleye pollock, pacific cod, yellowfin sole and rock sole (Weeks 1997). These species are thought to account for roughly 75 per cent of discards in the Bering Sea, Aleutian islands and Gulf of Alaska. These requirements will go into effect for pollock and cod from January 1998. The requirements for the other two

[36] In contrast, in most fisheries around the world where quota restrictions are used as a key management measure, landing over-quota fish is forbidden and discarding permitted.

species come into effect in five years time (Weeks 1997). While the potential effectiveness of such a policy in the fishery is uncertain, it is expected that the policy will result in a considerable reduction in discards (Pautzke 1995)

The advantage of such a policy, provided it is effective, is that the total fishing mortality is accounted for and the potential for incorrect TACs is reduced. This benefit needs to be weighed against the costs imposed by the system. Forcing fishers to land all of their catch can increase the costs of fishing and reduce the revenue per trip (as the hold will partly be filled with lower valued species that would otherwise have been discarded). As noted in the previous chapter, some level of discarding may actually produce greater social benefits than zero discarding.

The effectiveness of such a policy in reducing the level of discarding will depend largely on the level of enforcement and the degree of the penalty. If the probability of capture is low or the penalty low relative to the potential gains that could be made through discarding then the prohibition of discarding may not be sufficient to actually prevent discarding. Effective monitoring of compliance will also add costs. The annual surveillance budget in Norway is between 18 and 20 million NOK (about \$1.6 million to \$1.8 million) (Olsen 1997). While it is difficult if not impossible to enforce the discard ban completely, compliance in Norway is thought to be generally good as fishers generally support the management plan (Isaken 1997). Such a policy was thought to be easier to carry out in Norway than other many other countries due to the high proportion of single- or few-species fisheries (Isaken 1997).

Despite the prohibition of discarding quota species in New Zealand, discarding is still thought to continue. Consequently bycatch management in New Zealand relies on other mechanisms to reduce the incentive to discard. These other mechanisms include deemed values, quota trading, permissible over- and under-runs, landing against another's quota and quota substitution.

A prohibition on discarding may also create other problems. A ban on discarding at sea in Namibian waters has lead to problems of disposal of the unwanted fish on land. These have resulted in additional costs as the fish must be processed for either human use or reduced to meal (Everett 1995).

5.2.7 Voluntary surrender of over-quota catch

The landing and voluntary surrender of over-quota catch without penalty is a further option for overcoming some of the problems associated with ITQ management. As mentioned above, such a system is in place in New Zealand where fishers are able to surrender over-quota catch to the management authority (Baulch and Pascoe 1992).

A difficulty with the surrender option is that the system is open to abuse. If fishers are allowed to land their over-quota catch, then they also have an opportunity to dispose of it on the black market. Given the nature of fishing, most activity is not easily observed and inspection usually takes place on the quay side. Over-quota catch found by inspectors could be surrendered. If no inspectors are present, the catch could still be sold and not recorded. If the catch can be sold, then there is no incentive to change fishing patterns and, while the level of discarding is reduced, the potential quota over-run may be increased.

A further difficulty is the potential for receivers of surrendered fish to offer fishers some secret incentive. If there are a number of alternative receivers, as might be the case if the management agency contracts out the task of handling over-quota catch, some may offer under-the-table prices to encourage fishers to surrender their catch to them. This price may encourage some fishers to continue catching fish as before.

The final difficulty with the voluntary surrender of over-quota catch as a management option is the lack of incentive for fishers to comply. From Chapter 3, there are strong economic incentives to discard the fish at sea if the net price received by landing the fish are negative. With zero sale price and non-zero costs of landing the fish then any fish destined for surrender would, from the fisher's perspective, be better off discarded. While social pressures may increase the cost of discarding (Sutinen and Kuperan 1995), these may need to be substantial to encourage fishers to incur the additional costs involved in landing over-quota catch.

The major advantage of the system is that it provides a method for legally disposing of the catch to fishers who have genuinely attempted to find quota (either to lease or buy) but who have been unsuccessful. With imperfections in the quota market, there may be a period of time between the decision to land and the realisation that quota is unavailable. Under such circumstances the fisher has lost the opportunity to discard at sea and would face possible prosecution unless he or she were able to surrender the catch.

Hence, like the other policies mentioned above, voluntary surrender of catch may produce either positive or negative incentives to reduce the level of discarding.

5.3 Economic measures

Economic measures are aimed at changing the economic incentives faced by fishers to land or discard their fish. As noted in Chapter 3, the decision to land or discard fish is largely a function of the net price received. Economic incentives change the net price.

The key forms of economic incentives used or theorised are taxes and subsidies. These provide direct incentives or disincentives to fishers to discard. Related to these is the concept of the deemed value and quota substitution. These provide less direct incentives to land or discard fish.

5.3.1 Taxes and subsidies

Taxes and subsidies have two potential roles in reducing the level of bycatch in fisheries – correcting for externalities and reducing the incentives to highgrade.

A tax can be used to correct the problem of externalities, and is often proposed as a solution to reducing externalities such as pollution (Pearce and Turner 1990, Fredman and Boman 1996, Perman, Ma and McGilvray 1996). Imposing a tax on the generation of the externality causes the producer to take these costs into consideration when planning their production level. In the example in Chapter 3 of the tuna fishery, imposing a charge on the incidental take of dolphins affected the production decisions. Imposing a charge on the bycatch species in the cod/haddock example would have also had similar results.

A practical difficulty with the imposition of taxes on discards, however, is that of measuring the level of discards. It is unrealistic to expect fishers to accurately record the level of discarding if they were to then be taxed on the basis of these records. Instead, a comprehensive observer programme would be required. Theoretically the tax revenue could be used to offset all or some of the cost of the observer programme. However, if an optimal tax rate was set such that the optimal level of discarding was achieved, then the cost of the observers would be a net cost to society (even if funded from the tax revenue) as the tax revenue should reflect the compensation to society for the damage created by the fishing activity. The net cost of the observer programme needs to be compared with the costs and effectiveness of other policies and a cost effectiveness analysis conducted[37].

A series of taxes and subsidies on landings may be able to reduce the incentives to highgrade catch (Anderson 1994). As these will be applied to landings rather than catches they reduce the problems mentioned above.

From Chapter 3 it was seen that highgrading is rational behaviour if

$$(5.1) \qquad (P_H - P_L)) > \frac{1}{\alpha_H}\left(\frac{C'}{y} + C_D\right)$$

where P_H and P_L are the prices received for the high valued and low valued grades respectively, α_H is the proportion of the catch that is the higher valued grade, C' is the marginal cost per unit of effort, y is the average catch per unit of effort and C_D is the cost of discarding. Hence, highgrading is rational if the price difference between the grades is greater than the marginal cost per unit catch, $(1/\alpha_H)(C'/y)$, (that is, the cost of capturing an additional unit to replace the discarded catch) and the cost of discarding, $(1/\alpha_H)C_D$.

A tax on the higher valued size class can reduce the price differential and thereby reduce the incentives to highgrade. The optimal level of tax is that which reduces the price so that

$$(5.2) \qquad (P_H - t_H - P_L)) = \frac{1}{\alpha_H}\left(\frac{C'}{y} + C_D\right)$$

---

[37] Cost effectiveness analysis compares the costs and outcomes of various policies. The most desirable policy is that which has the least cost per unit of outcome.

where t_H is the tax per unit of landing on the higher valued size class.

An alternative to taxing the higher valued grades of fish is to subsidise the lower valued grades to provide an incentive to land and market these fish. Based on equation 5.1, the optimal subsidy is that which increases the price such that

$$(5.2) \qquad \left(P_H - (P_L + s_L)\right) = \frac{1}{\alpha_H}\left(\frac{C'}{y} + C_D\right)$$

where s_L is the subsidy per unit of landing on the lower valued size class.

A potential danger of subsidising low grade species is that if the subsidies are too high there may be an incentive to discard higher valued fish in order to land the lower valued fish (Anderson 1994). This is referred to as lowgrading (Anderson 1994). This will occur if

$$(5.3) \qquad \left(P_H - (P_L + s_L)\right) < -\frac{1}{\alpha_L}\left(\frac{C'}{y} + C_D\right)$$

That is, the price difference between the grades is negative (i.e. the price of the higher valued grade is less than the lower valued grade when subsidies are added), and less than the marginal cost per unit catch of the lower grade size class, $(1/\alpha_L)(C'/y)$, and the cost of discarding, $(1/\alpha_L)C_D$.

A theoretically optimal combination of taxes and subsidies can be estimated that reduce the incentives to both highgrade and low grade. From equation 5.1, there would be no incentive to highgrade provided that

$$(5.4) \qquad \left((P_H - t_H) - (P_L + s_L)\right) = \frac{1}{\alpha_H}\left(\frac{C'}{y} + C_D\right)$$

From this, the relationship between the tax and the subsidy can be expressed as

$$(5.5) \qquad t_H = \left(P_H - P_L\right) - \frac{1}{\alpha_H}\left(\frac{C'}{y} + C_D\right) - s_L$$

Similarly, from equation 5.3 there would be no incentive to lowgrade provided that

$$(5.6) \qquad t_H = \left(P_H - P_L\right) + \frac{1}{\alpha_L}\left(\frac{C'}{y} + C_D\right) - s_L$$

These two conditions can be depicted graphically (Figure 5.2). A combination of taxes and subsidies between the two lines will provide no incentives to either highgrade or lowgrade. A combination of taxes and subsidies that fall below the lower condition would result in positive incentives to highgrade, whereas a combination that fell above the upper condition would result in positive incentives to low-grade.

The balanced budget line in Figure 5.2 is given by $t=(aH/aL)s$. If the combination of tax and subsidies is above this line then the effect will be a net tax. If the combination is below this line then the effect will be a net subsidy to the fishery. Theoretically, it is possible to have a combination of tax and subsidies that will be effectively neutral (i.e. no net tax or subsidy) while preventing size-related discarding.

In practice, fishers will catch the different size classes in differing proportions. Hence, it will not be possible to derive a set of taxes and subsidies that will be neutral for all fishers. Some fishers (those that catch a greater proportion of small fish) will incur a net subsidy whereas other fishers (those that catch a greater proportion of large fish) will incur a net tax. Similarly, it may not be possible to find a combination of subsidies and taxes that fall within the 'no discarding' zone for all fishers. However, it would be expected that a combination could be found that is applicable to the majority of fishers (Anderson 1994).

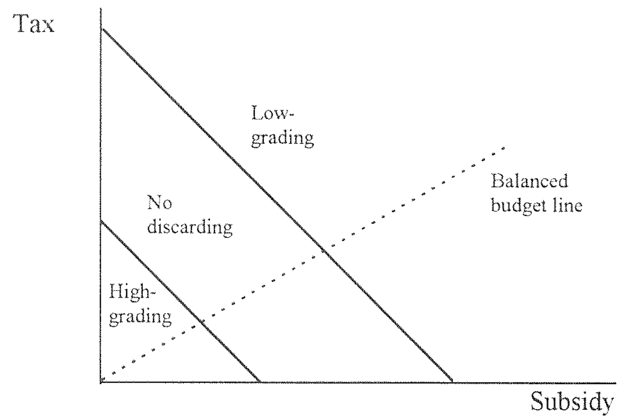


Figure 5.2 Effects of tax and subsidy combinations on discarding
Source: Anderson (1994)

From an administrative viewpoint, recording the catch by size class could be difficult and costly. As in the case of the size class based quotas mentioned previously, recording this additional information will impose increased costs on both fishers and managers. Anderson (1994) suggests that the records of each individual could be aggregated over the year and either a tax bill or subsidy cheque sent at the end of the year. While the delays may reduce the administrative burden, they may also remove the incentives as the incidence is not incurred until later. Fishers may discount future subsidies/taxes so that the incentives they create are reduced. A tax/subsidy scheme may also create incentives to mis-report the size class of the catch, further distorting the effectiveness of the scheme.

Subsidising the landing of small size classes or low valued species removes the incentives to avoid capturing these fish (Baulch and Pascoe 1992). Again from Chapter 3, the costs of discarding encourage fishers to adopt gear that avoids smaller sized fish. If this incentive was removed, then a larger quantity of small, low grade fish may be caught. Hence a policy of subsidisation may lead to an increase in capture and landings of low grade fish, and hence may lead to growth overfishing.

5.3.2 Deemed values

The concept of the 'deemed value' was developed in the New Zealand quota management system. The deemed value approach focuses on the economic disincentives that motivate fishers to discard, rather than land, over-quota catch. As noted earlier, fishers incur costs in landing fish that reduce the net price received. Discarding also imposes a cost on the operator, since the fish have to be manually separated. The deemed value approach is aimed at providing an incentive to land the fish by ensuring that the net price is not negative, but not high enough to provide a financial incentive to target the fish.

The basis of the deemed value approach is that the market price of the fish can be thought as consisting of two parts – the incentive price and the deemed value – as seen in Figure 5.3 (Baulch and Pascoe 1992). The incentive price is the price the operator must receive in order to ensure that the net price is greater than or equal to zero. Hence the incentive price is equivalent to the landing costs. The deemed value is the difference between the market price and the incentive price, and is equivalent to the net price received.

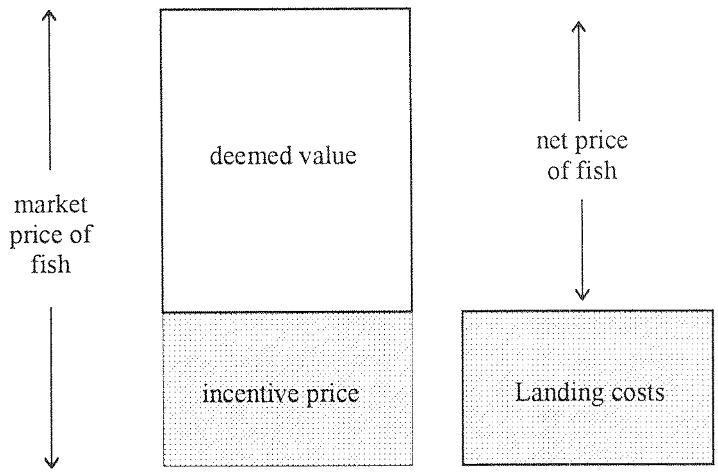


Figure 5.3 Components of market price
Derived from Baulch and Pascoe (1992)

The deemed value is paid by fishers to the management authority for landing and selling their over-quota catch. As such, it is similar in many respects to a tax on the over-quota catch. Under the deemed value system, the operator should retain sufficient returns to cover the costs of landing the over-quota catch (e.g. sorting, packing and marketing the fish) without providing incentives for further catching of the fish (as the net price received should be about zero).

In New Zealand, the deemed value is the preferred bycatch management system (Wheeler, Bradford, Collins, Duncan, Wilson and Young 1992). The fisher may sell over-quota catch in the same way as other landings, but pay the deemed value back to the management authority.

The New Zealand deemed values are determined in two stages. First, a base price is calculated for each species as the average of the export price and port price in the previous year. The deemed values are then calculated as a proportion (between 30 and 70 per cent) of the base price. The proportions vary by species, based on the subjective probabilities of any particular species/stock combination being discarded as well as the expected quota lease price. Lower proportions, and therefore lower deemed values, are placed on fish that have a higher likelihood of being discarded. In most cases, the proportion is also chosen such that the deemed value is greater than the expected quota lease price. This is to encourage fishers to acquire quota rather than pay the deemed value (Baulch and Pascoe 1992).

As an example, the incentive prices and deemed values for a few key New Zealand quota species in 1991 are given in Table 5.1. The incentive prices in Table 5.1 are derived under the assumption that the actual return received by fishers for landing unintentional bycatch is equal to the estimated base price. Given that the deemed value is fixed for periods at a time and is based on previous market conditions, the actual incentive price received by the fisher will depend on the actual price received on the day the fish was landed. If market prices are higher than the base price, the incentive price will be higher than the landing costs and the fisher will have an increased incentive to land the fish. However, if the market price is less than the base price, then the incentive price will be less than the landing costs and the fisher will have an incentive to discard.

Table 5.1 Incentive prices and deemed values for key New Zealand species, 1991

species	average export price a (NZ$/kg)	average port price b (NZ$/kg)	base price c =(a+b)/2 (NZ$/kg)	proportion of base price d	deemed value e = c*d (NZ$/kg)	incentive price f = c - e (NZ$/kg)
Gemfish	2.61	1.00	1.80	0.40	0.72	1.08
Orange Roughy	2.71	2.00	2.35	0.70	1.65	0.70
Trevally	2.02	1.58	1.80	0.60	1.08	0.72
Flatfish	3.66	3.03	3.35	0.40	1.34	2.01

Source: Baulch and Pascoe (1992)

A particular problem facing the use of the deemed value approach in the New Zealand fin fish fishery is that there are two types of fishers. First, a considerable proportion of the quota is held by a relatively small number of vertically-integrated processors. These processors run their own fleet, but also buy fish from other fishers. High value adding during processing may act as an additional inducement to company owned fleets to land over-quota fish and pay the deemed value (Sissenwine and Mace 1991). To some extent this is taken into consideration in the use of export prices in determining the base prices. However, fishers who sell only to the market or to the processors may receive a lower price than the base price. The resulting net price they receive may not provide sufficient incentive to land the fish.

The deemed value can also influence the working of the quota market. If the deemed value is determined incorrectly such that it is less than the quota lease price plus transactions costs, no one would lease quota since their over-quota catch can be sold and the lower deemed value paid. This in turn would drive the quota lease price to a lower level. At this lower quota lease price, some fishers may prefer to use, rather than lease, their quota. If the deemed value was greater than the lease price plus transactions costs under these circumstances, then no one would pay the deemed value, since the net return is less than the additional costs (Baulch and Pascoe 1992).

Baulch and Pascoe (1992) suggest that a way around this problem is to calculate the incentive price directly based on the costs of landing the fish. Landing costs are likely to be fairly constant over the year whereas the incentive price resulting from the deemed value approach fluctuates over the year. The idea proposed by Baulch and Pascoe (1992) is that fishers calculate the deemed value to be paid to the management authority by deducting the fixed incentive price from the market price received. With the constant incentive price approach, the operator is likely to land the product irrespective of the market price, as long as the incentive price is calculated correctly and landing costs are, in fact, relatively constant.

While this approach overcomes some of the problems raised above, it is still subject to problems of its own. Vertically integrated processors will have an incentive to use 'artificially' low prices when paying for the catch from their own boats. This will reduce the deemed value payment and effectively increase the incentive price. Independent harvesters and processors will face the same incentive, and therefore they will be motivated to collude to reduce reported prices to artificially low levels (Baulch and Pascoe 1992).

In some cases, the market price may not be sufficient to cover even the incentive price, and the net price would be negative. In such a case, these fish would be discarded. However, under these circumstances, these fish would have been discarded even in an unregulated fishery.

The deemed value system was established in New Zealand principally to deal with the problems of discarding due to lack of quota and does not address the problem of highgrading. Highgrading will still occur while the fisher still has quota for the species. As any catch landed will be deducted from the quota, the fisher can not use other measures such as deemed values. Hence the incentive for highgrading will still persist.

Highgrading may also continue to occur even if the quota had been exceeded (so that there is no opportunity cost in landing the small fish in terms of the quota used). If the net price received for the smaller fish was negative (i.e. the costs of landing the fish exceed the market value), then forcing the fisher to pay a deemed value will further increase the costs of landing the fish. Fish will only be landed provided that the expected net price equals or exceeds the deemed value.

A deemed value system would also provide few benefits where bycatch is being discarded due to higher prices being expected later in the season (that is, price dumping). In these circumstances, all fish may be discarded irrespective of size.

A system of deemed values will most likely reduce some, but not all of the problem of unrecorded catch in the fishery. In particular, it could have an impact on the level of discarding of over-quota catch. A potential benefit of the deemed value approach is that it is in part self funding. Those fishers who are exceeding their quota are paying more for the bycatch management policy than those who fishing within their quota. However, the extent to which the deemed value revenue would offset management costs is difficult to ascertain (Baulch and Pascoe 1992).

5.3.3 Quota substitution

Under a quota substitution policy fishers would be allowed to land and receive the revenue from bycatch in return for forfeiture of quota for another species. Since the operator is able to land and market the over-quota fish, there is no incentive to discard it provided the conversion rates between species are such that the value of the fish sold is no less than the value of the quota exchanged. Once the quota for a group of related species have been used, the operator must avoid capturing these fish, or else lease additional quota.

The potential advantages of quota substitution are best illustrated by a simple hypothetical example, taken from Pascoe *et al* (1994). In this example, we will assume that there is a fisher with quota holdings of 20 tonnes for species A and 5 tonnes for species B. These two species occupy the same habitat and are generally caught at the same time. For simplicity, we will also assume that the two species have similar market values, say £2/kg. The relative abundance of these species varies from year to year. In the current year, the fisher is catching 1 tonne of species B and 3 tonnes of species A each day fished. As a result, the operator has effectively a shortage of quota for species B, since the species B quota will be filled well before the species A quota.

The fisher has caught 15 tonnes of species A and 5 tonnes of species B so far over the year. Consequently he or she has filled his/her quota for species B but still has unfilled quota for species A. In the absence of a quota substitution mechanism, the fisher is entitled to catch the remaining 5 tonnes of species A, but at the same time must discard a bycatch of 1.7 tonnes of species B (assuming that he or she is unable or unwilling to lease additional quota). Given the current catch rates, this will require a further 5 days of effort, assuming that it is still profitable to land only species A.

If the fisher was able to substitute quota of one species for another at a substitution rate of 1 to 1 then the remaining 5 tonnes of species A quota could be used to land 3.75 tonnes of species A and 1.25 tonnes of species B. This would require only a further 4 days fishing. Once the quota has been filled for both species A and species B, the fisher can then target some other species group for which he or she still holds quota (or stop fishing if all his/her quota has been used).

A comparison of the total catch, discarding and revenue under the two alternatives is given in Table 5.2. From this table, it can be seen that the same revenue can potentially be achieved with less total catch than by discarding the over-quota catch. The quota over-run was reduced from 35 per cent without quota substitution (that is, 1.7 tonnes) to 25 per cent with quota substitution (that is, 1.25 tonnes). This is also achieved with a lower level of effort, and hence a lower level of costs.

Table 5.2 The potential effect of a quota substitution policy

	no quota substitution				quota substitution			
Species	catch (tonnes)	landed (tonnes)	discarde (tonnes)	revenue (£)	catch (tonnes)	landed (tonnes)	discarde (tonnes)	revenue (£)
A	20.00	20.00	0	40 000	18.75	18.75	0	37 500
B	6.70	5.00	1.70	10 000	6.25	6.25	0	12 500
TOTAL	26.70	25.00	1.70	50 000	25.00	25.00	0	50 000

Source: Pascoe *et al* (1994)

The amount of quota of a particular species that needs to be given up when landing associated bycatch caught without quota is given by the quota substitution rate. The substitution rate needs to provide an incentive for fishers to use unfilled quota to land incidental bycatch but to prevent them from using the quota to target other species. In New Zealand, substitution rates are based largely on biological criteria (Pascoe *et al* 1994). As a result, there may be instances where the opportunity cost of the quota given up (that is, the value that could be gained by using that quota to catch the quota species) is greater than the value of the bycatch landed. In these cases, the operator would not have an incentive to land the bycatch using quota substitution and would continue to discard, or in the New Zealand case, land the species under an alternative bycatch management option.

Providing an economic incentive to land the bycatch involves ensuring that the opportunity cost of the quota used to land the bycatch is less than the value of the bycatch. However, this substitution rate must be sufficiently high to encourage fishers to lease in quota for the bycatch species, if available. Catch can be over the individual quota for one operator based on his or her quota holdings, but quota may be available from other fishers in the fishery. Where quota is available for the bycatch species, it is preferable to have the catch landed with quota so as to reduce the potential overall over-quota catch in the fishery. A substitution rate that does not encourage quota leasing will reduce the need for quota leasing and possibly prevent the quota market from becoming established.

The substitution rate should also be sufficiently high to prevent fishers using quota of one species to target another species for which they do not hold quota. Providing an incentive to target other species will most likely lead to higher catches of these other species, with possible longer term impacts on stocks and future profits.

Determining a substitution rate that is applicable in all circumstances is not possible as fishers have different cost structures, catch different size grades of fish and have different market destinations. In addition, costs and prices vary over time. Consequently, it is better to estimate the upper and lower bounds on rates that provide the correct incentives under most circumstances. The actual substitution rates applied in the fishery may be set within these bounds at the discretion of managers and industry, based on their expectations of fishers' behaviour.

Following Pascoe *et al* (1994), to create an incentive to substitute quota to land over-quota bycatch, the value (opportunity cost) of the quota given up in the substitution of must be of lesser value to the fisher than the value of the landed bycatch, such that

$$(5.7) \qquad QSR_{a,b}V_b \le P_a - L_a$$

where $QSR_{a,b}$ is the number of units of species b quota used to land species a, V_b is the value (opportunity cost) of a unit of species b quota, P_a is the price received for species a, and L_a is the cost of landing a unit of species a. Hence the right hand side of equation 5.7 represents the net price received for the bycatch species. From this, an upper bound for the substitution rate can be defined, given by

$$(5.8) \qquad QSR_{a,b} \le \frac{P_a - L_a}{V_b}$$

The value of the quota to be substituted is best defined by the quota lease value rather than the average profitability of the catch of that species. The quota lease value could be expected to represent the marginal value of the quota. In theory, this could be expected to equal the average profitability of the marginal unit of quota. In the case of a target species, the lease price should reflect all of the costs of fishing. For a bycatch species, the lease price should reflect the price less marketing and crew costs (Pascoe *et al* 1994).

In order to minimise TAC over-runs, it is desirable that fishers are provided with an economic incentive to seek additional quota (where available) to land bycatch rather than by quota substitution. This requires that the value of the quota that is to be substituted, V_b, is greater than the lease value of quota of the bycatch species, V_a, assuming it is available. That is,

$$(5.9) \qquad QSR_{a,b}V_b \ge V_a$$

From this:

$$(5.10) \qquad QSR_{a,b} \ge \frac{V_a}{V_b}$$

It should generally be possible to set a substitution rate that falls within or on the bounds defined in equations 5.8 and 5.10. The highest possible value of quota is equal to the unit return from incidental bycatch when only the landing costs need to be considered. Hence:

$$(5.11) \quad V_a \leq P_a - L_a$$

for any species so that the lower bound (equation 5.10) can never exceed the upper bound (equation 5.8).

Experiences in other countries

Quota substitution policies of varying degree have been applied in Iceland, New Zealand and Canada. However, the systems vary considerably in the degree of complexity and usefulness.

In Iceland, fishers are able to substitute catch quota for one demersal species for that of another within a limit of 5 per cent of their individual quota holdings (Willmann 1996). The exchange is expressed in terms of cod equivalents. The cod equivalent value of each species is calculated on the basis of its market values relative to that of cod at the beginning of the season. Changes in market values over the year, however, can alter the incentives to substitute quota. In 1989, an increase in the price of Greenland halibut resulted in many vessel owners converting cod quota for use in landing halibut (Skarphédinsson 1993 cited in Willmann 1996).

In New Zealand, quota substitution is not available for all species and at all times. Substitution is only permissible between certain species that have a close biological association (Bauckham 1992). To be eligible for substitution, a 'bycatch problem' must be declared to exist, although the management authority has no obligation to declare species eligible for quota substitution if such a problem is declared (Bauckham 1992). A 'bycatch problem' exists when the actual catch ratio of bycatch species to target species is greater than the ratio of the TACs of the two species, and such a disparity is likely to lead to a significant TAC over-run.

Where species are declared eligible for quota substitution, a fixed conversion rate is determined. The conversion rate is based on the expected TAC over-run of the bycatch species and the extent to which the target species TAC would need to be reduced to prevent this over-run (Bauckham 1992). The greater the potential TAC over-run of the bycatch species, the greater the amount of target species quota that must be substituted.

Declaration of quota substitution options, however, does not guarantee that substitution will be permitted. Fishers must apply to substitute quota of the target species for the bycatch species. Each proposal is sent for scientific review in which the potential for the TAC to be exceeded is reconsidered, logbook records are examined to ensure that the bycatch was taken with the appropriate substitute species, and the market value of the quota being offered is examined to ensure that there are no economic incentives prompting the exchange[38]. If the offer is accepted after the review, the quota substitution is permitted. If it is not accepted, the fisher is sent a bill for the deemed value of the over-quota catch (Pascoe *et al* 1994).

This is a complex process. Each offer of substitution is assessed individually. The fisher is also required to pay an administration fee for each offer. This acts as a disincentive for fishers to offer to substitute quota. Since the value of the quota is not considered in setting the conversion rates, there may be economic incentives to choose to pay the deemed value or discard rather than substitute quota. Where there are economic incentives to choose to substitute quota, these incentives may result in the substitution offer being rejected.

In contrast to New Zealand, the Canadian system is fairly simple. In Canada, quota substitution has been implemented as the principal bycatch management programme in the Scotia-Fundy groundfish fishery. Conversion rates between the three major species are established based on the relative prices of the fish and costs associated with catching them. The conversion rates are determined with the intention that both discarding and targeting is discouraged (Liew 1991).

An upper bound on the conversion rates is determined based on the assumptions that the catch is incidental. In this case, only the share to the crew is deduced from the port price. A lower bound is determined on the assumption that the catch is targeted. In this case, the crew share and the average variable cost of catching the fish is deduced from the price (Liew 1991). The conversion rates are fixed for a given season between these two bounds.

While the Canadian approach avoids the complexities of the New Zealand approach, it still may have some limitations. If prices vary considerably over the season, then the incentives to target or discard would also change since the conversion rates are fixed. For example, if the price of haddock was low at a particular time, over-quota catch of haddock may still be discarded rather than use the more valuable pollock quota. This is a similar problem to highgrading, where low value grades are discarded to avoid using the quota. This problem may be reduced by increasing the frequency of setting the conversion rates. However, it is likely that the conversion rates will never perfectly reflect the actual price differentials for all fishers.

As with deemed values, quota substitution is really only useful in dealing with over-quota catch. It is not likely to be a useful tool to reduce highgrading.

The principal advantage of quota substitution is that it may result in a lower TAC over-run than other policy options, while also providing incentives to land rather than

[38] If indeed there is an economic incentive to substitute quota then the substitution may be refused. If there isn't an economic incentive then it is most likely that some other aspect of the bycatch management plan will be used by the fisher (such as deemed value). Hence the New Zealand system is largely self defeating.

discard over-quota catch. Quota substitution results in the quota of all related species being reduced simultaneously. By using the remaining target species quota to cover the bycatch, the target species quota is also filled earlier. As a result, the operator ceases to target that species, and hence ceases to take bycatch for which no quota is held. With a deemed value system, the operator has incentives to fill the target species quota with the target species, resulting in a higher catch of both target and bycatch species.

5.3.4 Value based ITQs

A key cause of highgrading under ITQ fisheries is that the limit is expressed in terms of total quantities that can be landed. Turner (1996) and Willmann (1996) have suggested an alternative formulation of the ITQ system that could overcome this problem - value based ITQs. Defining the quota in terms of value reduces the incentives to highgrade the catch.

Under a traditional ITQ system, a unit of quota has an opportunity costs based on the higher valued components of the catch (provided that the quota is actually binding). Landing the lower valued size classes results in the returns from the use of the quota being less than the opportunity cost. Hence there exists an incentive to discard lower valued size classes, as discussed in Chapter 3 and in the above section on taxation.

By specifying the quota in terms of value, the opportunity cost of a unit of quota is the same regardless of the size class. The same amount of quota would be used in landing, say, 2 tonnes of small fish at £1/kg as 1 tonne of large fish at £2/kg. As the bycatch of the smaller sized fish has already been caught, and to replace the value of that catch with larger fish would require additional effort (and hence additional cost), the incentive created by value based ITQs is to land the smaller fish rather than discard them.

Value based ITQs may also reduce the incentive to price -discard compared with quantity based ITQs. With a limit on the quantity of catch that may be landed, fishers may discard their catch (both high and low valued grades) if they discover that prices are low and they expect to be able to get greater returns from using their quota at a later date (taking into account the increased costs involved). With a value based ITQ, the fisher only has the value of the catch deducted from their ITQ. If prices are low they are not penalised by landing their catch.

Value based ITQs may also remove the need for fishers to have a portfolio of quotas for individual species in a multispecies fishery. This removes the problem of incompatible TACs, and thereby reduces the problems associates with over-quota catch of bycatch species. The incentive structure would be to minimise the costs of harvest rather than maximising the value of the catch (Willmann 1996). Fishers would target the species that produced the greatest value per unit of effort. Hence the quota would be taken with the lowest possible fishing effort and consequently the lowest total cost. Under ideal conditions, if one species was being overly targeted the increase in its supply would reduce its price making other species relatively more attractive (Willmann 1996).

While the incentive structure of a value based ITQ system is more compatible with a policy aiming at optimal discarding behaviour by fishers than traditional ITQs, such a system may fail to realise the intended TACs. Underlying the TAC and the ITQ must be some form of quantity of fish removed. Changes in prices could effectively alter the implicit quantity TAC during the year, particularly if prices fell. In such a case the effective TACs would be higher than anticipated. This might be avoided by adjustments of the total allowable value within the year but the anticipation by fishers of such changes might create an undesirable incentive for fishers to use their value based ITQs early on in the season. As there are also no explicit quantity quotas on individual species, there may also be difficulties in ensuring that the implicit TAC for individual species is not over run. Willmann (1996) suggests that single-species total allowable values (the value equivalent of a total allowable catch) may still be required for species that are likely to be more profitable than others. While such a system will still help to reduce highgrading, it will still result in over-quota catch and discarding.

These problems needs to be traded off against the benefits of having a greater level of information on catch composition while still providing incentives for fishers to improve their economic performance.

A value based ITQ system will not totally eliminate highgrading. As demonstrated in Chapter 3, a profit maximising fisher will highgrade even in the absence of any regulation if the net price is negative or if there is a hold constraint that is binding. Such discarding, however, is optimal from the point of view of the fishery provided that it does not result in externalities to other groups within or outside the fishing industry.

A final potential difficulty with a value based ITQ system is that it places an explicit limit on the revenue that can be earned by fishers. While quantity based ITQs also restrict the earning capacity of fishers, they are able to plan their fishing operation to achieve the greatest returns they can given the quantity constraint. Hence there exists only an implicit revenue limit as better fishers could probably still earn more than less efficient fishers. Fishers may be hesitant to accept an explicit limit on their gross earning capacity[39] and fishery managers may be hesitant to apply such a limit on the fishery as a whole. Such a system does, however, still offer incentives for better fishers to lower their harvesting costs and increase their net earnings and hence promote increased efficiency in the fishery.

---

[39] As with quantity based quotas, fishers are still able to increase their individual earning limit by purchasing more quota. However, there remains a cap on total fishery revenue.

5.3.5 Effort reduction

Effort reduction falls loosely under the heading of economic measures, but it could equally have fallen under the heading of technical or administrative measures. Effort can be reduced through a number of management policies such as ITQs or buyback programmes. The method of effort reduction is not going to be considered in this section as the benefits and costs of alternative effort reduction methods are described in depth in most fisheries economics textbooks (for example, see Anderson 1977 or Cunningham, Dunn and Whitmarsh 1985).

The effects of effort reduction on the level of bycatch and discarding have been discussed in earlier chapters, especially Chapters 3 and 4. Effort reduction is usually pursued for other reasons, such as increasing the level of fishery profits and/or reducing the catch in the short term so that a higher sustainable level of catch can be achieved in the long term. As such, effort reduction is not a bycatch management policy *per se*. However, reducing the level of effort in a fishery is likely to have substantial beneficial effects on the level of bycatch.

The effects of effort reduction on the level of bycatch and discarding were illustrated in Chapter 3 in Figure 3.4. This figure is reproduced below in a modified form (Figure 5.4) to re-emphasise the benefits of effort reduction.

Assume for the purposes of example that the bycatch species has no commercial value and is fully discarded. The open access equilibrium level of effort is given as E_1. At this level of effort B_1 bycatch is caught and discarded on a sustainable basis. Reducing the level of effort to E_2 will result in a short term reduction in discarding, but as the stock of the bycatch species recovers both bycatch and discarding would increase. In the long run an effort level of E_2 would be associated with a sustainable level of discarding equal to B_2.

Reducing the level of effort further to E_3 (the level which roughly maximises total fishery profits), the level of discarding will again decrease in the short term. In the longer term the stock size would further increase, but (as seen in the previous chapters) the sustainable yield decreases as the stock approaches the environmental carrying capacity. hence the long term level of bycatch and discarding would be given by B_3. In this case, the long run sustainable level of discarding that is associated with the maximum sustainable level of profits is less than the open access level.

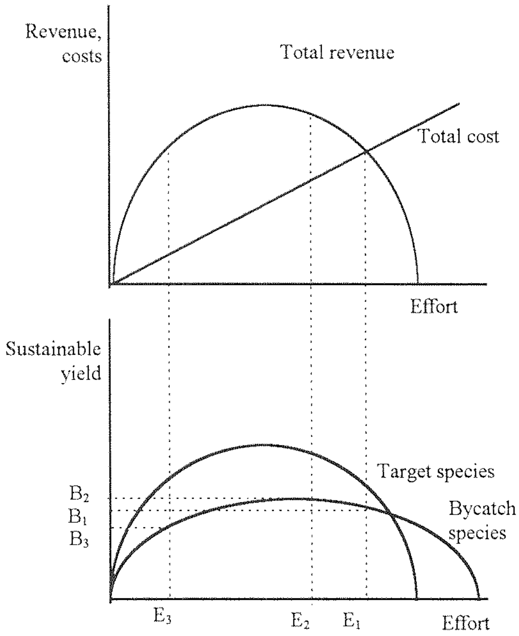


Figure 5.4 Effects of effort reduction on the level of discarding

This is not necessarily always the case. In the examples of the tuna/dolphin fishery and the cod/haddock fishery given in Chapter 4, the long run optimal sustainable level of discarding was greater than the open access level. In such instances, however, the higher level of discarding were associated with higher stock levels. In the classification system of Hall (1995a) in Chapter 2, such discarding could be considered sustainable or biologically insignificant discarding.

5.4 Chapter summary

There exists a wide range of options for reducing discarding in commercial fisheries. These include technical measures (e.g. bycatch reduction devices), administrative arrangements (e.g. quota trading) and economic instruments (e.g. taxes and subsidies).

The technical measures have largely been designed to reduce the level of bycatch, and thereby the level of discards. Considerable success have been achieved in reducing the level of bycatch of seabirds, turtles and marine mammals through changes in the gear or the way the gear is employed. Some success has also been observed in developing gear that can separate bycatch species from target species, particularly in some shrimp fisheries. As these fisheries are major contributors to the global level of discards, reductions of bycatch in these fisheries could result in a significant reduction in the level of global discarding.

The use of the modified gear, however, has placed a cost on fishers in the form of reduced catch rates. This cost varies considerably from fishery to fishery.

Most of the non-technical measures have been developed to counter the problems created by individual transferable quotas. These problems include discarding due to over-quota catch and the increased incentive to highgrade. While a wide variety of policy options exist, none can totally eliminate economic incentives to discard. However, a number of policies have successfully reduced the incentives to discard in some fisheries.

Most of the problems faced by the non-technical measures were of a practical nature rather than theoretical. In particular, most mechanisms would require a large increase in the amount of information collected. This is likely to impose additional costs on both fishers and society as a whole. However, a judgement has been made in several fisheries managed under ITQs that the costs imposed by these systems do not outweigh the benefits they produce in terms of reduced discarding.

Of all the methods examined effort reduction is likely to be the most successful approach to reducing bycatch and discarding in the short run. In the long run, provided effort can be contained, discarding may increase as a result of stock increases of the bycatch species. However, from both a conservation and economic perspective such an increase may be desirable.

6. Conclusions

Fisheries bycatch and discarding is not a new problem, and has long been recognised as a normal part of fishing activity. However, the growth of marine fisheries production over the last 50 years has been accompanied by a substantial increase in the level of discards. In total, between 18 and 40 million tonnes of fish are thought to be discarded annually. With commercial landings from marine fisheries being about 80 million tonnes a year, discarding represents about 20 per cent of the total world marine catch.

Many of the discards consist of small or juvenile fish of commercial species. If left uncaught, these fish could potentially increase future yields. With marine fisheries production at or near its peak and many of the world's fisheries being exploited at or above their full capacity, reducing the level of discards of small and juvenile fish has become increasingly important in terms of stock conservation. Further, the discarding of potentially consumable fish is seen as a waste of protein in a world where millions of people remain undernourished.

Bycatch and discards of non-commercial species has also taken greater prominence. Many of these species have non-market values that are not being considered in the production decisions of fishers. Increased concern for environmental issues has seen green issues take an increasingly important role in public policy formulation in many economically advanced countries.

Discarding is a common feature of most commercial fishery. Individual fishers have an incentive to discard fish if the price they expect to receive is less than the cost of landing and marketing the catch. As many small fish attract low prices, fishers have an economic incentive to discard rather than land these fish. Further, where the amount of catch a fisher can land is limited by the hold capacity, incentives exist to discard the least valuable fish. While such discarding is rational behaviour by the individual, the level of discarding in the fishery as a whole may differ from the socially optimal level of discarding. The incidental capture and discarding of fish may produce costs for other groups in society including other fishers in the same or overlapping fisheries, fish consumers and others in society who may experience some disutility as a result of discarding some species. If these costs were incurred by fishers then it is likely that they would alter their own harvesting strategies accordingly.

Fisheries management has led to an increase in discarding in some cases by changing the economic incentives facing fishers. While both input and output controls can affect the incentives to discard, policies such as individual transferable quotas (ITQ) have attracted considerable attention as these appear to provide the greatest incentives to discard fish. In response to this, a range of additional management policies are often imposed in ITQ fisheries to try and provide an additional set of economic incentives to land the fish to counterbalance the incentives to discard. In addition, a range of administrative measures have been devised to reduce the transactions costs associated with quota trading and leasing. The success of these policies has been limited as it is not possible to develop a policy that can deal with every eventuality. However, the incentives to discard can be reduced through a combination of these policies. Further research is required in this area to develop new policies (or improve existing ones) that provide the appropriate set of incentives to fishers. One such potential new policy may be the use of value based ITQs. These have the theoretical potential to reduce highgrading in ITQ fisheries as well as provide the same economic incentives that are often seen as the main attraction of ITQ management.

Technical solutions to the problems of discarding have focused on the development of gear to reduce the level of unwanted catch. While changes in gear technology can reduce the physical level of discards, this can impose additional costs on commercial fishers. In many cases, the use of the gear results in lower catch rates of the target species. Fishers have an incentive to adopt selective gear provided that the costs imposed by the gear are less than the expected cost savings (in terms of reduced sorting time and discarding costs). If fishers do not voluntarily adopt the fishing gear then it is likely that the costs imposed by the gear outweigh the benefits at the level of the individual fisher . However, forcing fishers to use the gear may still be desirable from the viewpoint of society as a whole if the previous level of discarding was creating externalities that were not being considered by the fishers in their production decisions. These costs and benefits will need to be assessed on a case by case basis.

Area and seasonal closures have also been implemented in some fisheries to reduce the level of unwanted catch or to provide a refuge for species that are being adversely affected by incidental harvesting. In some fisheries, particularly shrimp fisheries, seasonal closures have proved beneficial in both reducing the catch of juvenile animals and increasing the value of the catch. In other fisheries, seasonal and area closures have increased the costs to the fishers. Consequently, the economic effectiveness of using technical measure to reduce bycatch need to be considered on a fishery by fishery basis.

From an economic perspective, the most desirable approach to address the problems associated with discarding is often to reduce the total level of effort. Effort reduction is likely to have the greatest positive impact among the available bycatch management options in terms of food security, conservation and enhancing fishers' incomes (Everett 1997). This can only be achieved through effective management. Reducing effort will have an immediate short run effect on the level of discarding, reducing it below the current levels. In the longer term, however, the level of discarding may increase even if effort is effectively contained. However, if this does occur, it will be the result of increased stocks of the bycatch species. This in itself can be viewed as a benefit rather than a cost. Reducing the level of effort will also have beneficial effects on the stocks of the target species, as well as improve the long run level of incomes generated by the fishery.

FAO estimates that about a 60 per cent reduction in the level of discards can be achieved by the year 2000 (Everett 1995). This can be achieved through the increased use of existing selective fishing gear, the development of new gear and the development of fisheries management policies that create the correct incentives for fishers (Everett 1995).

In most fisheries, however, the total elimination of discards will be neither feasible nor desirable. There is an optimal level of discarding that takes into account the benefits produced by discarding (i.e. the catch of the commercial species and the savings in storage, preservation and transport costs) and the costs imposed by discarding. This will only be zero under extreme circumstances. Reducing discards below this optimal level may result in society not achieving the greatest benefits possible from the use of the fisheries resources.

References

Alverson, D. L., and Hughes, S. E. 1995. 'Bycatch: from emotion to effective natural resource management', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 13-28.

Alverson, D. L., Freeberg, M. H., Murawski, S. A. and Pope, J. G. 1994. *A global assessment of fisheries bycatch and discards*. FAO Fisheries Technical Paper 339, FAO. Rome.

Anderson, L. G. 1977. *The Economics of Fisheries Management*. Baltimore: John Hopkins University Press.

Anderson, L. G. 1994. 'An economic analysis of highgrading in ITQ fisheries regulation programs', *Marine Resource Economics* 9(3) 209-226.

Anderson. L. G. 1997. 'Definition of highgrading', Posting to the 'FISHFOLK' mail list <fishfolk@mitvma.mit.edu>, 6 October 1997.

Andrew, N. L., Jones, C., Terry, C. and Pratt, R. 1995. 'Bycatch of an Australian stow net fishery for school prawns (*metapenaeus macleayi*)', *Fisheries Research* 22(1): 119-136.

Andrews, B. 1990a. 'Unregulated fisheries: small group recommendations', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 13-14.

Andrews, B. 1990b. 'Limited entry', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 42-43.

Androkovich, R. A. and Stollery, K. R. 1992. *A stochastic dynamic programming model of bycatch control in fisheries*, CEMARE Research Paper P59, CEMARE, University of Portsmouth, UK.

Armstrong, D. A., Wainwright, T. C., Jensen, G. C., Dinnel, P. A. and Anderson, H. B. 1993. 'Taking refuge from bycatch issues: red king crab (*Paralithodes camtschaticus*) and trawl fisheries in the Eastern Bering Sea', *Canadian Journal of Fisheries and Aquatic Science* 50(9): 1993-2000.

Arnason, R. 1994. 'On catch discarding in fisheries', *Marine Resource Economics* 9(3):189-207.

Arnason, R. 1995. On selectivity and discarding in an ITQ fishery, paper presented at the 5th European Association of Fisheries Economists' Bioeconomic Modelling Workshop, Edinburgh, 24-27 October 1995.

Barlow, J., Baird, R. W., Heyning, J. E., Wynne, K., Manville, A. M, Lowry, L. F., Hanan, D. and Sease, J. 1990. A review of cetacean mortality in coastal fisheries of the eastern North pacific and USSR far east. Paper SC/90/G28 presented at the IWC workshop on mortality of cetaceans in passive fishing nets and traps, La Jolla, California Oct. 22-25, 1990.

Bauckham, A. P. 1992. Operational policy for by-catch trade-off scheme, Unpublished paper submitted to the MAFFish Senior Fisheries Management Committee, Ministry of Agriculture and Fisheries, Greta Point.

Baulch, K. and Pascoe, S. 1992. *Bycatch management options in the south east fishery*, ABARE Research Report 92.18, ABARE, Canberra.

Beltestad, A. K. and Misund, O. A. 1995. 'Size selection in purse seines', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 227-233.

Berghahn, R., Waltemath, M. and Rijnsdorp, A. D. 1992. 'Mortality of fish from the bycatch of shrimp vessels in the North Sea', *Journal of Applied Ichthyology* 8:293-306.

Beverton, R. J. H. and Holt, S. J. 1957. 'On the dynamics of exploited fish populations', *Fishery Investigations Series II* 19:1-533.

Boyce, J. R. 1996. 'An economic analysis of the fisheries bycatch problem', *Journal of Environmental Economics and Management* 31: 314-336.

Brander, L. 1996. 'Draggers and bycatch', Posting to the 'FISHFOLK' mail list <fishfolk@mitvma.mit.edu>, 29 October 1996.

Branstetter, S. 1996. 'Re: More Bycatch', Posting to the 'FISHFOLK' mail list <fishfolk@mitvma.mit.edu>, 7 November 1996.

Brewer, D. and Eayrs, A. 1994. 'New prawn and fish trawl gear reduces non-target bycatch', *Australian Fisheries* 53(3): 9-11.

Brewer, D., Eayrs, A., Mounsey, R. and Wang, Y. 1994. 'Assessment of an environmentally friendly, semi-pelagic fish trawl', *Fisheries Research* 26(3-4): 225-237.

Broadhurst, M. K. and Kennelly, S. J. 1994. 'Reducing the bycatch of juvenile fish (mulloway *Argyrosomus hololepidotus*) using square-mesh codends in the Hawkesbury River prawn trawl fishery, Australia', *Fisheries Research* 19(3-4): 321-331.

Bublitz, C. G. 1995. 'Mesh size and shape: reducing the capture of undersized fish', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 95-99.

Campbell, H. F. 1991. 'Estimating the elasticity of substitution between restricted and unrestricted inputs in a regulated fishery: A probit approach', *Journal of Environmental Economics and Management* 20: 262-274.

Campbell, H. F. and Lindner, R. K. 1990. 'The production of fishing effort and the economic performance of licence limitation programmes', *Land Economics* 66: 56-66.

CEMARE. 1996. *Current economic policies and their impacts on fisheries overexploitation*, CEMARE Report to World Wide Fund for Nature (UK), CEMARE, University of Portsmouth.

Chaing, A. C. 1984. *Fundamental Methods of Mathematical Economics*, McGraw-Hill International, Singapore.

Chen, Y. and Gordon, G. N. G. 1997. 'Assessing discarding at sea using a length-structured yield per recruit model', *Fisheries Research* 30(1-2): 43-55.

Chiasson, Y. P., Vienneqau, R., DeGrace, P., Campbell, R., Herbert, M. and Moriyasu, M. 1993. 'Evaluation of catch selectivity of modified snow crab (*Chionoecetes opilio*) conical traps'. *Canadian Technical Report on Fisheries and Aquatic Science* 1930.

Chopin, F., Inoue, Y. Matsushita, Y., and Arimoto, T. 1995. 'Sources of accounted and unaccounted fishing mortality', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 41-47.

Clark, C. W. 1985. *Bioeconomic Modelling and Fisheries Management*, John Wiley and Sons, New York.

Clark, C. W. 1990. *Mathematical Bioeconomics: the optimal management of renewable resources* (2nd edition), John Wiley and Sons, USA.

Clark, J., Griffin, W., Clark, J. and Richardson, J. 1991. 'Simulated economic impacts of TED regulations on selected vessels in the Texas shrimp fishery', *Marine Fisheries Review* 52(2): 1-8.

Clucas, I. J. 1997a. 'Reduction of fish wastage - an introduction' in: Clucas, I. and James, D. (Eds), *Papers Presented at the Technical Consultation of Reduction of Wastage in Fisheries*, FAO Fisheries Report No. 547, Supplement, FAO, Rome, 1-14.

Clucas, I. J. 1997b. 'The utilisation of bycatch/discards' in: Clucas, I. and James, D. (Eds), *Papers Presented at the Technical Consultation of Reduction of Wastage in Fisheries*, FAO Fisheries Report No. 547, Supplement, FAO, Rome, 59-67.

Copes, P. 1986. 'A critical review of the individual transferable quota as a device in fisheries management', *Land Economics* 62: 278-291.

Coffey, B. T. and Grace, R. V. 1990. A preliminary assessment of the impact of driftnet fishing on oceanic organisms: Tasman Sea, South Pacific, January 1990. Brian T. Coffey and Associates Limited: EIA/SDF (GP01/1990).

Correy, T. and Williams, E. 1995. 'Bycatch: Whose issue is it anyway', *Nor'easter* 7(1), 1-7.

Crestin, D. 1997. 'Re: ITQs', Posting to the 'FISHFOLK' mail list <fishfolk@mitvma.mit.edu>, 4 October 1997.

Christensen, S. 1995. 'Potential bioeconomic impact of reduced mortality of codend escapees of the shrimp fishery in the Davis Strait', *ICES Journal of Marine Science* 52(5): 843-851.

Cunningham, S. 1993. 'Outcome of the workshop on individual quota management', in Cunningham, S. (Ed), *The use of individual quotas in fisheries management*, OECD, Paris.

Cunningham, S., Dunn, M. R., and Whitmarsh, D. 1985. *Fisheries Economics: An Introduction*. Mansell Publishing Limited.

Dann, T. and Pascoe, S. 1994. *A bioeconomic model of the northern prawn fishery*. ABARE Research Report 94.13, ABARE.

Davis, O. A. and Kamien, M. I. 1977. 'Externalities, information and alternative collective action', in: Dorfman, R. and Dorfman, N. S. (Eds), *Economics of the Environment (2nd edition)*, W. W. Norton and Company, New York, 111-129.

Dayton, P. K., Thrush, S. F., Agardy, M. T. and Hofman, R. J. 1995, 'Environmental effects of marine fishing', *Aquatic Conservation: Marine and Freshwater Ecosystems* 5: 205-232.

Dewees, C. M. 1990. 'Multispecies fishery challenges with individual transferable quotas (ITQs)', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 49-50.

Dewees, C. M. and Ueber, E. 1990. 'Introduction', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 7-8.

Die, D. J., Restrepo, V. R. and Hoenig, J. M. 1988. 'Utility per recruit modelling: a neglected concept', *Transactions of the American Fisheries Society* 117: 274-281.

Dilday, W. E. 1995. 'US diplomatic involvement in fisheries bycatch issues', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 301-305.

Dorsey, E. 1977. 'Trip limits for Gulf of Maine cod to start May 1 amid continuing concerns', *New England Fisheries News* 3:2-3, April 1977.

Duthie, A. 1997. 'Canadian efforts in responsible fishing operations: the impact in the Canadian northern shrimp fishery and the success of bycatch devices in Canadian fisheries', in: Clucas, I. and James, D. (Eds), *Papers Presented at the Technical Consultation of Reduction of Wastage in Fisheries*, FAO Fisheries Report No. 547, Supplement, FAO, Rome, 99-116.

Edwards, S. F., Murawski, S. A. and Thunberg, E. 1997. 'Case 3: Bycatch of yellowtail flounder in the southern New England trawl fishery' in: National Marine Fisheries Service (Eds), *Managing The Nation's Bycatch: Priorities, Programs And Actions For The National Marine Fisheries Service* (Draft March 20, 1997) Available from: http://kingfish.ssp.nmfs.gov/bycatch/econstds.pdf

European Commission. 1996. *Agriculture and agro-industry, including fisheries: Programme of research and technological development 1991-94, third framework programme, synopsis of selected projects in the field of fisheries and aquaculture*, European Commission EUR 16482 EN, Luxembourg.

Evans, S. M., Hunter, J. E. Elizal and Wahju, R. I. 1994. 'Composition and fate of the catch and bycatch in the Farne Deep (North Sea) nephrops fishery' *ICES Journal of Marine Science* 51(2):155-168.

Everett, G. V. 1995. 'Fisheries bycatch and discards: a report from FAO', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 279-283.

Everett, G. V. 1997. 'Actions to reduce wastage through fisheries management', in: Clucas, I. and James, D. (Eds), *Papers Presented at the Technical Consultation of Reduction of Wastage in Fisheries*, FAO Fisheries Report No. 547, Supplement, FAO, Rome, 45-58.

FAO 1993. *Review of the State of the World Marine Fishery Resources*, FAO Fisheries Technical Paper No. 335, FAO, Rome.

FAO 1996. 'Global fishery production in 1994', FAO Report, FAO, Rome.

FAO 1997. 'Fisheries bycatch and discards', 22nd Session of the Committee on Fisheries, Rome, Italy 17-20 March 1997. FAO Document COFI/97/Inf. 7, Rome.

Fredman, P. and Boman, M. 1996. 'Endangered species and optimal environmental policy', *Journal of Environmental Management*, 47: 381-389.

Frost, H., Rogers, P., Valetin, G., Lantz, F., Lewy, P. And Vestergaard, N. 1993. *A Bioeconomic model of the North Sea multispecies multiple gears fishery* Vol. 1 South Jutland University Press, Esbjerg.

Garthe, S., Camphuysen, C. J. and Furness, R. W. 1996. 'Amounts of discards by commercial fisheries and their significance as food for seabirds in the North Sea', *Marine Ecology Progress Series* 136: 1-11.

Garthe, S. and Hüppop, O. 1994. 'Distribution of ship-following seabirds and their utilisation of discards in the North Sea in summer', *Marine Ecology Progress Series* 106: 1-9.

Gauvin, J. R., Haflinger, K. and Nerini, M. 1995. 'Implementation of a voluntary bycatch avoidance program in the flatfish fisheries of the Eastern Bering Sea', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow.* Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 79-85.

Griffin, W. L. and Oliver, C. 1991. *Evaluation of the Economic Impacts of Turtle Excluder Devices (TEDs) on the Shrimp Production Sector in the Gulf of Mexico*, MARFIN Project No. NA-87-WC-H-06139. Agricultural Economics Department, Texas A&M University College Station.

Gutting, R. E. Jr. 1997. 'The US shrimp embargo', INFOFISH International 2/97: 19-22.

Hall, M. A. 1995a. 'Strategic issues in managing fishery bycatches', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow.* Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 29-32.

Hall, M. A. 1995b. 'International panel on management solutions: discussion', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow.* Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 307-309.

Hanna, S. 1990. 'Mesh size regulations and bycatch in the west coast groundfish fishery', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 33-34.

Hanna, S. S. and Smith, C. L. 1993. 'Attitudes of trawl vessel captains about work, resource use and fishery management', *North American Journal of Fisheries Management* 13: 367-375.

Hannesson, R. 1993. *Bioeconomic Analysis of Fisheries*. Fishing News Books, UK.

Hannesson, R. 1996. *Fisheries Mismanagement: the Case of the North Atlantic Cod*, Fishing News Books, UK.

Hilborn, R. and Walters, C. J. 1992. *Quantitative Fish Stock Assessment: Choice, Dynamics and Uncertainty*. Chapman and Hall, New York.

Hill, B. J. 1992. 'Minimum legal sizes and their use in management of Australian fisheries' in: Hancock, D. A. (Ed.), *Legal sizes and their use in fisheries management, Australian Society of Fish Biology workshop , Lorne, 24 August 1990*, Bureau of Rural Resources Proceedings No. 13, Australian Government Publishing Service, Canberra.

Hill, B. J. and Wassenberg, T. J. 1990. 'Fate of discards from prawn trawlers in the Torres Strait', *Australian Journal of Marine and Freshwater Research* 41: 53-64.

Hillis, J. P., Fitzsimons, M., McEwan, V., Rogers, P. E., O'Connor, R. and Whelan, B. J. 1995. *Overall profit optimisation in the Irish Sea fisheries: Management, economic, socio-economic and biological study*, Fisheries Research Centre, Dublin, Ireland.

Hendrickson, H. M and Griffin, W. L. 1993. 'An analysis of management policies for reducing shrimp bycatch in the Gulf of Mexico', *North American Journal of Fisheries Management* 13(4):686-697.

Henwood, T. A. and Stuntz, W. E. 1987. 'Analysis of sea turtle captures and mortalities during commercial shrimp trawling', *Fisheries Bulletin* 85:813-17.

Hoagland, P. and Jin, D. 1997. 'A model of bycatch involving a passive use stock', *Marine Resource Economics* 12(1):11-28.

Holden, M. 1994. *The Common Fisheries Policy: origin, evolution and future*, Fishing News Books, Great Britain.

IFAD 1988. *Nigeria: Artisanal Fisheries Development Project; Appraisal Report*, Working Paper 7. IFAD (International Fund for Agricultural Development).

International Conference on Shrimp Bycatch 1992. *Proceedings of the International Conference on Shrimp Bycatch, May 24-27, Lake Buena Vista, Florida*, NOAA/NMFS, Tallahassee, Florida.

Isaksen, B. 1997. 'The Norwegian approach to reduce bycatch and avoid discards', in: Clucas, I. and James, D. (Eds), *Papers Presented at the Technical Consultation of Reduction of Wastage in Fisheries*, FAO Fisheries Report No. 547, Supplement, FAO, Rome, 89-93.

Jacobsen, J. A., Thomsen, B. and Isaksen, B. 1992. Survival of saithe (*Pollachius virens* L.) escaping through trawl meshes. ICES CM 1992/B:29.

Jensen, J. G. 1986. 'Recovery of bycatch from the shrimp fishery by the "Moma Transfer" method: a review', in FAO (Ed) *Fish Processing in Africa: Proceedings of the FAO Expert Consultation on Fish Technology in Africa*, FAO Fisheries Report No. 329 Supplement.

Jones, B. 1997. 'Re: Turtles, TEDs, etc.', Posting to the 'FISHFOLK' mail list <fishfolk@mitvma.mit.edu>, 21 June 1997.

Joyce, I. 1996. 'Shrimp bycatch utilisation', Posting to the 'FISHFOLK' mail list <fishfolk@mitvma.mit.edu>, 30 October 1996.

Kaiser, M. J. and Spencer, B. E. 1995. 'Survival of bycatch from a beam trawl', *Marine Ecology Progress Series* 126:31-38.

Keiser, R. K. 1976. *Species composition, magnitude and utilisation of the incidental bycatch of South Carolina shrimp fishery*. South Carolina Marine Resource Technical Report 16.

Kennelly, S. J. and Broadhurst, M. K. 1995. 'Fishermen and scientists solving bycatch problems: examples from Australia and possibilities for the Northeastern United States', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 121-128.

Laist, D. W. 1995. 'Marine debris entanglement and ghost fishing: a cryptic and significant type of bycatch', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 33-39.

Lave, L. B. and Seskin, E. P. 1977. 'Air pollution and human health', in: Dorfman, R. and Dorfman, N. S. (Eds), *Economics of the Environment (2nd edition)*, W. W. Norton and Company, New York, 422-449.

Lien, J. 1995. 'Conservation aspects of fishing gear: cetaceans and gillnets', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 219-224.

Liew, D. 1991. Determination of conversion ratios to use for charging overruns in one species against allocations in another in the Scotia-Fundy mobile gear individual quota fleet, Unpublished paper, Department of Fisheries and Oceans, Scotia-Fundy Region, Canada.

Liggins, G. W. and Kennelly, S. J. 1996. 'Bycatch from prawn trawling in the Clarence River estuary, New South Wales, Australia', *Fisheries Research* 25(3-4), 347-367.

Lowman, D. 1990. 'The effect of limited entry on bycatch issues', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 41-42.

Marakovitis, D. M. and Considine, T. J. 1996. 'An empirical analysis of exposure-based regulation to abate toxic air pollution', *Journal of Environmental Economics and Management* 31: 337-351.

McQuaid, J. 1996. 'Gulf shrimpers take a pounding', *Oceans of Trouble*, The Times-Picaynue.

Miller, R. J. 1995. 'Options for reducing bycatch in lobster and crab pots', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 163-168.

Muharaj, V. and Recksiek, C. 1991. 'The bycatch from the artisanal shrimp trawl fishery, Gulf of Paria, Trinidad', *Marine Fisheries Review* 53(2): 9-15.

Murawski, S. A. 1990. 'Mesh size regulations and discards: some observations from the North Atlantic', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 31-32.

Murray, J. D., Bahen, J. J. and Rulifson, R. A. 1992. 'Management considerations for bycatch in the North Carolina and south east shrimp fishery', *Fisheries* 17(1): 21-26.

Nishemura, W. and Nakahigashi, S. 1990. 'Incidental capture of sea turtles by Japanese research and training vessels: results of a questionnaire'. *Marine Turtle Newsletter* No. 51. Sanyo Hydrographic Survey Co. Ltd and Hiwasa Chelonian Museum, Japan.

Newton, G. 1995. 'Bycatch, the non-target catch of fishing' *Fish Facts No. 4*, Department of Primary Industries and Energy, Canberra.

Newton, G. and Causbrook, B. 1995. 'Fishing methods and gear' *Fish Facts No. 5*, Department of Primary Industries and Energy, Canberra.

Newton, G. and Truelove, K. 1995. 'Seabirds and fishing' *Fish Facts No. 10*, Department of Primary Industries and Energy, Canberra.

Northbridge, S. P. 1991. *Driftnet fisheries and their impact on non-target species: a world-wide review*. FAO Fisheries Technical Paper No. 320, FAO, Rome.

Oig, H. 1984. 'Seabird mortality incidental to the Japanese salmon gill-net fishery', in: Croxal, J. P., Evans, P. G. H. and Schreiber, R. W. (Eds) *Status and conservation of the World's seabirds*. International Council for Bird Preservation Technical Publication No. 2.

Olsen, V. J. 1995. 'Ways in which Norway is solving the bycatch problem', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 289-291.

Olsen, H. E. 1997. 'Appendix 1 - Surveillance programme monitoring of sensitive areas in Norwegian waters', in: Clucas, I. And James, D. (Eds), *Papers Presented at the Technical Consultation of Reduction of Wastage in Fisheries*, FAO Fisheries Report No. 547, Supplement, FAO, Rome, 94-97.

Opaluch, J. and Bockstael, N. 1984. 'Behavioural Modelling and Fisheries Management' *Marine Resource Economics* 1(1): 105-115.

Oro, D. and Ruiz, X. 1997. 'Exploitation of trawler discards by breeding seabirds in the north-western Mediterranean: differences between the Ebro Delta and the Balearic Islands areas', *ICES Journal of Marine Science* 54: 695-707.

Pascoe, S. 1993. 'ITQs in the south east fishery', *Marine Resource Economics* 8(4): 395-401.

Pascoe, S. 1994. *Benefits and costs of single species conservation in a multispecies fishery: the case of the Australian eastern gemfish*, CEMARE Research Paper P73, CEMARE, Portsmouth.

Pascoe, S. 1997. *A preliminary bioeconomic model of the UK component of the fisheries of the English Channel*, CEMARE Research Paper P112, CEMARE, Portsmouth.

Pascoe, S., Lancaster, A., Klaer, N. and Battaglene, T. 1994. *Quota substitution as a bycatch management option in the south east fishery*, ABARE Project No. 33.011.

Pautzke, C. G. 1995. 'Management perspectives on waste and discards in North Pacific fisheries', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 269-273.

Pearce, D. W. and Turner, R. K. 1990. *Economics of Natural Resources and the Environment*, Harvester Wheatsheaf, Great Britain.

Pender, P., Willing, R. and Cann, B. 1992. 'NPF bycatch a valuable resource?', *Australian Fisheries* 51(2) 30-31.

Pereyra, W. T. 1995. 'Midwater trawls.and the Alaskan Pollock fishery: a management perspective', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 91-99.

Perman, R., Ma, Y. and McGilvray, J. 1996. *Natural Resource and Environmental Economics*, Longman, Singapore.

Poiner, I. and Harris, A. 1994. 'The incidental capture and mortality of sea turtles in Australia's northern prawn fishery' in: James, R. (Ed) *Proceedings of the Australian Marine Turtle Conservation Workshop*, Australian Nature Conservation Agency, 127-35.

Pooley, S. 1990. 'Limited entry and Hawaii's fisheries interaction problem', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 40-41.

Prado, J. 1997. 'Technical measures for bycatch reduction', in: Clucas, I. and James, D. (Eds), *Papers Presented at the Technical Consultation of Reduction of Wastage in Fisheries*, FAO Fisheries Report No. 547, Supplement, FAO, Rome, 25-44.

Revill, A.1997. *The Biological and Economic Impacts of Discarding in the UK (East Coast) Brown Shrimp fishing Flee*t, Report to MAFF, University of Lincolnshire and Humberside, Grimsby, UK.

Richards, J. 1990. 'Seasons and joint catch', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint cątch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 17-20.

Robins, J. B. 1995. 'Estimated catch and mortality of sea turtles from the east coats otter trawl fishery of Queensland, Australia', *Biological Conservation* 74: 157-167.

Robinson, C. and Pascoe, S. 1996. 'Input controls and input substitution in the English Channel beam trawl fishery', in Franquesa, R (Ed) *Proceedings of the VIII Annual Conference of the European Association of Fisheries Economists*, Ministerio de Agricultura, Pesca Y Alimentacion, Madrid, 135-150.

Robinson, C. and Pascoe, S. 1997. Fisher behaviour: exploring the validity of the profit maximising assumption, Paper presented at IX[th] conference of the European Association of Fisheries Economists Quimper, France, 28-30 April 1997.

Romine, T. 1995. 'Perspectives on the Global Fisheries Crisis', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 61-70.

Ruff, L. E. 1977. 'The economic common sense of pollution' in: Dorfman, R. and Dorfman, N. S. (Eds), *Economics of the Environment (2nd edition)*, W. W. Norton and Company, New York, 41-58.

Rulifson, R. A., Murray, J. D. and Bahen, J. J. 1992. 'Finfish catch reduction is south Atlantic shrimp trawls using three designs of bycatch reduction devices', *Fisheries* 17(1): 9-19.

Saila, S. 1983. *Importance and assessment of discards in commercial fisheries*, FAO Circular 765, FAO, Rome.

Sampson, D. B. 1994. 'Fishing tactics in a two species fisheries model: the bioeconomics of bycatch and discarding', *Canadian Journal of Fisheries and Aquatic Science* 51(12): 2688-2694.

Sangster, G. I., 1994. A review of the survival of fish escaping from fishing gears. Report to the sub-group on methodology of fish survival experiments. Common Meeting of the International Council for the Exploration of the Sea (ICES) CM-ICES 1994/B:8.

Sangster, G. I., Lehmann, K., and Breen, M. 1996. 'Commercial fishing experiments to assess the survival of haddock and whiting after escaping from four sizes of diamond mesh cod-ends', *Fisheries Research* 25(3-4): 323-345.

Sano, O. 1978. 'Seabirds entangled in salmon drift nets', *Enyo* 30: 1-4.

Saville, A. 1980. The assessment and management of pelagic fish stocks: discussion and conclusion of symposium, in: ICES (Ed), *Rapports et proces Verbaux des Reunion du Conseil International pour L'Exploration de la Mer*, ICES 177: 513-517.

Sheridan, P. F., Browder, J. A. and Powers, J. E. 1984. 'Ecological interactions between penaeid shrimp and bottomfish assemblages' in: Gulland, J. A. and Rothschild, B. J. (Eds), *Panaeid shrimp - their biology and management*. Fishing News Books, Farnham, 235-58.

Sissenwine, M. P. and Mace, P. M. 1992. 'ITQs in New Zealand: the era of fixed quota in perpetuity', *Fishery Bulletin* 90(1): 147-160.

Skarphédinsson, K. 1993. 'Fisheries management in Iceland', in: Neilsen, J. R. and Helgason, T. (Eds) *Multispecies fisheries management: Proceedings of a symposium in Hirtshals, May 22-23 1992, Nord.* 173-188.

Smith, C. 1990. 'Limited entry: small group recommendations', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 43-46.

Smith, T. P. 1995a. 'Solving the bycatch problem: an economic perspective', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 53-59.

Smith, W. T. 1995b. 'Reduction of halibut bycatch and associated mortality in the Bearing Sea cod fishery', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 203-209.

Soldal, A. V. 1993. 'Survival of gadoids that escape from a demersal trawl', *ICES Marine Science Symposia* 196: 122-127.

Somers, I. and Wang, Y. 1997. 'A simulation model for evaluating seasonal closures in Australia's multispecies northern prawn fishery', *North American Journal of Fisheries Management* 17(1):114-130.

Squires, D. 1987. 'Fishing effort: its testing, specification, and internal structure in fisheries economics and management', *Journal of Environmental Economics and Management* 14: 268-282.

Squires, D., Kirkley, J. and Tisdell, C. 1995. 'Individual transferable quotas as a fisheries management tool', *Reviews in Fisheries Science* 3(2):141-169.

Stevens, B. G. 1995. 'Crab bycatch in pot fisheries: causes and solutions' in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 151-158.

Sutinen, J. G. and Anderson, P. 1985. 'The economics of fisheries law enforcement', *Land Economics* 61(4): 387-397.

Sutinen, J. G. and Kuperan, K. 1995. 'A socioeconomic theory of regulatory compliance in fisheries', in: Liao, D. (Ed) *International Co-operation for Fisheries and Aquaculture Development: Proceedings of the 7th Biennial Conference of the International Institute of Fisheries Economics and Trade*, Volume 1. National Taiwan Ocean University, Keelung, Taiwan, R.O.C., 189-203.

Suuronen, P. 1995. 'Codend size-selection: good concept, but does it really work?', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 107-114.

Suuronen, P., Erickson, D. L. and Orrensalo, A. 1996. 'Mortality of herring escaping from pelagic trawl codends', *Fisheries Research* 25(3-4): 305-321.

Terry, J. M. 1997. 'Case 1: halibut bycatch in the Alaska groundfish fishery', in: National Marine Fisheries Service (Eds), *Managing The Nation's Bycatch: Priorities, Programs and Actions For The National Marine Fisheries Service* (Draft March 20, 1997) Available from: http://kingfish.ssp.nmfs.gov/bycatch/econstds.pdf

Turner M. A. 1996. 'Value based ITQs', *Marine Resource Economics* 11(2): 59-70.

Turner, S. 1990. 'Effects of seasonal management options on joint catches', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 16-17.

Ueber, E. 1990. 'Using mesh sizes to reduce discards', in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 30-31.

Walter, U. and Becker, P. H. 1997. 'Occurrence and consumption of seabirds scavenging on shrimp trawler discards in the Wadden Sea', *ICES Journal of Marine Science* 54: 684-694.

Ward, J. M. 1994. 'The bioeconomic implications of a bycatch reduction device as a stock conservation management measure', *Marine Resource Economics* 9(3): 227-240.

Ward, J. and Macinko, S. 1993. Using theory: rethinking fisheries bycatch problems. Paper presented at the International Conference on Fisheries Economics, Bergen, Norway, May 26-28 1993.

Warren, B., Ess, C. and Swenson, E. 1997. 'Managing bycatch and discards: a review of progress and challenges in the United States', in: Clucas, I. and James, D. (Eds), *Papers Presented at the Technical Consultation of Reduction of Wastage in Fisheries*, FAO Fisheries Report No. 547, Supplement, FAO, Rome, 69-88.

Wassenberg, T. J. and Hill, B. J. 1990. 'Partitioning of material discarded from prawn trawlers in Moreton Bay', *Australian Journal of Marine and Freshwater Research* 41: 27-36.

Weeks, H. 1997. 'Full retention/discards in fisheries', Posting to the 'FISHFOLK' mail list <fishfolk@mitvma.mit.edu>, 27 August 1997.

Western Australian Department of Fisheries 1996. *State of Western Australian Fisheries, 1995-96*, Western Australian Department of Fisheries, Perth.

Wheeler, B., Bradford, J., Collins, C., Duncan, A., Wilson, B., and Young, H. 1992. *Sustainable Fisheries Tiakina nga Taonga a Tangaroa*, Report of the fisheries task force to the Minister of Fisheries on the review of fisheries legislation, Ministry of Agriculture and Fisheries, Wellington.

Wickens, P. A. 1995. *A review of operational interactions between pinnipeds and fisheries*, FAO Fisheries Technical Paper 346, FAO Rome.

Willen, J. E. 1990. 'ITQs and the bycatch problem' in: Dewees, C. M. and Ueber, E. (Eds) *Effects of different fishery management schemes on bycatch, joint catch and discards: summary of a national workshop*, California Sea Grant College Report No. T-CSGCP-019, California Sea Grant College, University of California, La Jolla, 50-51.

Willmann, R. 1996. A value based individual transferable quota scheme - a preliminary examination of its suitability as a fisheries management technique', paper presented at the 8th Biennial Conference of the International Institute of Fisheries Economics and Trade, Marrakech, Morocco, 1-4 July 1996.

Wyman, E. 1995. 'Selective groundfish pots offer solutions to bycatch problems', in: Alaska Sea Grant College Program (Ed), *Solving bycatch: considerations for today and tomorrow*. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, 169-173.

Varian, H. R. 1990. *Intermediate Microeconomics: A modern approach (2nd edition)*, W. W. Norton and Company Inc., USA.

Villegas, L and Dragovich, A. 1984. 'The Guianas-Braxil shrimp fishery, its problems and management aspects, in: Gulland, J. A. and Rothschild, B. J. (Eds), *Panaeid shrimp - their biology and management*. Fishing News Books, Farnham.

Vestergaard, N. 1996. 'Discard behaviour, highgrading and regulation: the case of the Greenland shrimp fishery', *Marine Resource Economics* 11(4): 247-266.

The increase in commercial fisheries production over the last 50 years has been accompanied by an increase in the level of incidental catch and discarding of a number of species. Approximately one-quarter of the marine commercial catch destined for human consumption is discarded at sea. This has aroused the concern of a number of groups in society, including environmentalists, humanitarians and fishers themselves. This paper examines the economic incentives to discard fish as well as the effects of different management policies on these incentives. The concept of an optimal level of discarding is discussed taking into account the externalities that can be created by discarding. Finally, the paper reviews the effectiveness of various measures – technical, administrative and economic – to reduce the level of discarding.

ISBN 92-5-104043-5 ISSN 0429-9345

9 789251 040430

M-43 W6929E/1/11.97/1700