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Abstract

We reconstruct marine fisheries catches for the Federal Republic of Germany within their North Sea Exclusive Economic Zone (EEZ) equivalent waters from 1950-2010. ICES landings statistics are used as a reported baseline, and then adjusted using information from ICES stock assessment working group reports, national data, and expert knowledge to estimate unreported landings, recreational and subsistence catches and major discards. Brown shrimp (*Crangon crangon*) contribute the most to unreported landings and discards. Atlantic herring (*Clupea harengus*) and European plaice (*Pleuronectes platessa*) are also important fisheries within the EEZ equivalent waters for the period 1950-2010. The reconstructed total catch of 8.3 million t from 1950-2010 was approximately 59% higher than the EEZ-adjusted baseline reported ICES landings of 5.2 million t. The reconstructed total catch of invertebrates is over 3.8 million t, which is 96% higher than ICES baseline catch which is just over 1.9 million t. The reconstructed catch for all finfish species is over 4.5 million t and is 37% higher than the ICES baseline catch of 3.3 million t. These discrepancies are largely driven by discarded catches that are not accounted for in officially reported (ICES) data, which also form the globally reported data as presented by the Food and Agriculture Organization of the United Nations. Our results demonstrate the importance of comprehensively accounting for and disclosing fisheries data to the public (including discarded catches), and effectively monitoring Illegal, Unreported and Unregulated (IUU) catches.

Introduction

The Federal Republic of Germany is an economic power within the European Union (EU), with a population of 82.3 million (UN 2013). After World War II, Germany was divided into the Federal Republic of Germany (West Germany) and the Democratic Republic of Germany (East Germany), but reunified in 1990 (Figure 1). This division affected the way in which fisheries data were reported. East Germany and West Germany reported their data separately until reunification in 1990. During this time, East Germany had very little influence on fisheries in the North Sea. Most of the landings from East Germany were in the Baltic Sea, the Kattegat and the Skagerrak, and not within the EEZ equivalent waters of the North Sea (ICES sub-division IVb, Figure 1).

Germany has a mostly coastal fishing industry, extending into the deeper waters of the North Sea only to target a few species. German fisheries are currently a sector of minimal economic significance, not only for Germany as a whole but also for the coastal regions themselves. In 2010, the German fishing fleet consisted of 1,680 vessels with a tonnage of 67,765 GT and a total engine power of 159,714 kW (Anderson *et al.* 2012). This places Germany among the smaller fishing fleets in the European Union. German fishers in the North Sea mainly target brown shrimp (*Crangon crangon*), Atlantic mackerel (*Scomber scombrus*), European plaice (*Pleuronectes platessa*), common sole (*Solea solea*), saithe (*Pollachius virens*), Atlantic herring (*Clupea harengus*), whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*) and Atlantic cod (*Gadus morhua*).

The German commercial North Sea fleet mainly consists of inshore cutters that target brown shrimp and flatfish. In 2008, there were 38-42 vessels targeting flatfish, mainly European plaice and common sole (beam and otter trawls), 180-200 vessels targeting brown shrimp (beam trawls) and 7-8 vessels targeting demersal species, mainly cod and saithe (otter trawl and set net) fishing within ICES sub-division IVb (Ulleweit *et al.* 2010).

Figure 1. The German North Sea EEZ, as delineated by *Sea Around Us*, embedded within ICES subdivision IVb. Note, the German Baltic Sea EEZ is not highlighted here (see Rossing *et al.* 2010c; Zeller *et al.* 2011).

Atlantic herring, Atlantic cod and brown shrimp were the main species fished by Germany in the North Sea until the late 1960s, when there was a dramatic decline in the herring stock. In the late 1970s, the fishery was closed and reopened in the mid 1980s (ICES 2003). Despite a recovery of the herring stock in recent years, catches have never returned to previous levels. Brown shrimp, however, have remained an important fishery, with large catches throughout the 1950-2010 periods. Presently, European plaice is an important fishery that contributes a significant portion of current landings. There is a large decline in overall landings in the mid-1980s that likely coincides with collapsed Atlantic herring and Atlantic mackerel stocks, a strong decline in Atlantic cod, as well as a decrease in Total Allowable Catch (TAC) in the European plaice fishery (ICES 2002a, 2012a, 2012c). There have been some increases in European plaice, herring and brown shrimp landings (ICES 2002a).

While insignificant compared to commercial fisheries, catches of recreational fisheries along the North Sea coast are completely unreported. The North Sea is bordered by two German states (Bundesländer), which independently monitor their recreational fisheries (Strehlow *et al.* 2012). Niedersachsen has a common-right type policy for their recreational fisheries; therefore, no fishing license is required to fish and crab in territorial waters (Pawson *et al.* 2008; Strehlow *et al.* 2012). However, a permit is required for collecting shellfish(Pawson *et al.* 2008). Any fishing over and above those standards requires a license that is acquired through completion of an exam (Pawson *et al.* 2008). Catches from recreational fisheries are not reported to the government. The North Sea experiences large tidal ranges, with a mean spring range of 4 m, making boat angling a challenge and therefore it is not commonly practiced in this region (Strehlow *et al.* 2012). However, some shore angling does occur on the Frisian Islands in the state of Niedersachsen (Strehlow *et al.* 2012). Due to the strong tidal currents in the North Sea, charter vessels are relied on for recreational fishing and only few people go out on their own (H. Strehlow, pers. comm., Johann Heinrich von Thünen-Institut). These charter boats target Atlantic mackerel and cod from May-September (H. Strehlow, pers. comm., Johann Heinrich von Thünen-Institut). However, many tourists are no longer interested in charter fishing vessels due to long travel times to fishing grounds (approximately 2-3 hours each way), unpredictable weather and declines in catch rates of cod (H. Strehlow, pers. comm., Johann Heinrich von Thünen-Institut). Germany's recreational fisheries also consist of more historical fisheries such as tope shark fishing in Helgoland, mollusc harvesting along the Wadden Sea coast, as well as eel fishing (H. Strehlow, pers. comm., Johann Heinrich von Thünen-Institut). With a warming climate, several species of marine animals are extending their range northwards (Cheung *et al.* 2009), resulting in European sea bass becoming a target or incidental catch of German recreational fishers (H. Strehlow, pers. comm., Johann Heinrich von Thünen-Institut). While presently insignificant in catches, this may change in future decades.

The purpose of this report is to provide a comprehensive estimate of total fisheries catches, both officially reported and unreported catches, plus discards, in Germany's North Sea EEZ for the period 1950-2010. Germany's Baltic Sea catches were reconstructed elsewhere (Rossing *et al.* 2010c; Zeller *et al.* 2011). The ICES landings statistics provide a baseline time series for official reported landed catches for the period 1950-2010, and represent the entirety of globally reported catches as presented by FAO on behalf of Germany. Our reconstruction estimates the components of IUU catches, specifically a) high-grading; b) unreported landings; c) discards; and d) recreational; and e) subsistence catches. Our approach uses officially reported data by ICES, ICES reports, peer-reviewed literature, and personal communications with local scientists and fishers to reconstruct a total catch time series for 1950-2010.

Methods

The method for reconstructing German fisheries catch data for the North Sea involve using ICES official reported landings data as a 'reporting' baseline and estimating and adding what is termed Illegal, Unreported and Unregulated (IUU) catches. IUU are here defined as all catches (including discarded catches) taken from the marine ecosystem, yet not included in the officially reported ICES landings data. All estimates are based on quantitative, qualitative and historical information and follow the principles and approaches of catch reconstructions as outlined by Zeller *et al.* (2007).

Landings data

All of Germany's officially reported landings information is acquired through the ICES electronic landings database.[1] Catches are reported separately from 1950-1990 by West Germany and East Germany. From 1991 to 2010, landings are reported for a re-unified Germany. From 1950-1960, all landings data are reported as ICES sub-area IV or IIIa and IV. From 1961 onwards, the data are mostly allocated to sub-divisions IV a, IV b and IV c, with the exception of a few taxonomic groups. Germany's EEZ equivalent waters as defined here[2] in the North Sea falls into ICES sub-area IV, and more specifically sub-division IV b (Figure 1). Therefore, we determine the proportion of area of IV b from the total area of IV, and apply this to the landings for each year in area IV from 1950-1960, i.e., we assume area proportionality of catches as a simplifying assumption. In order to create a continuous time series for 'Germany', the former Federal Republic of Germany (West Germany), former Democratic Republic of Germany (East Germany) and Germany (present Federal Republic of Germany) are combined, i.e., we treat Germany as one entity for the entire time period (Figure 2).

In addition to reporting species-specific landings in more general management areas, East Germany and West Germany also reported some landings as general taxonomic groups such as 'flat fishes nei' for the earlier portion of the time series. In order to create a more detailed taxonomic breakdown for the 'flat fishes nei' catch, we calculated

[1] ICES http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx (Accessed March 5, 2012)

[2] *Sea Around Us* http://www.seaaroundus.org/eez/276.aspx (Accessed May 30, 2013)

annual proportions of all flat fish categories including 'flat fishes nei' but excluding common sole and European plaice, which are assumed to be reported accurately due to their commercial importance. These proportions are then applied to the 'flat fishes nei' catch of the corresponding year.

For our purposes, all officially reported landings are designated as large-scale commercial fisheries (or 'industrial'), with the exception of blue mussel (*Mytilus edulis*). Many of the commercial fisheries in Germany, such as those targeting European plaice, common sole and brown shrimp are fished using otter or beam trawls. We choose to designate any catch from a mechanized bottom trawl gear type as 'industrial' catch (following Martin 2012). Blue mussel landings are split into large-scale commercial (here called 'industrial') and small-scale commercial (here called 'artisanal'). In 1950, 60% of the blue mussel landings are designated as artisanal, and by 2010, 10% of the catch is artisanal. Proportions are interpolated for intervening years.

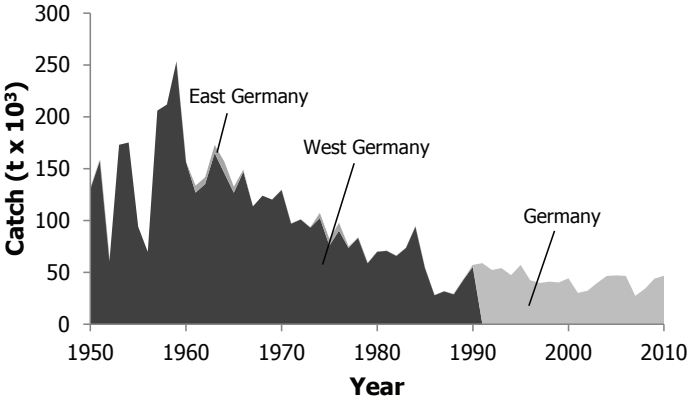

Figure 2. Reported landings for West Germany, East Germany and reunified Germany in ICES sub-division IV b for 1950-2010.

Illegal, Unreported and Unregulated catches

Unreported landings

Information on unreported landings can be acquired through ICES working group and stock assessments reports (ICES 2002a, 2002b, 2003, 2012a, 2012b, 2012c). These unreported landings are termed 'unallocated' and exist for many of the major fisheries Germany is engaged in. These data are often presented for all countries combined within the ICES sub-area IV. We assume proportionality between reported landings by country and 'unallocated' landings, and thus assign 'unallocated' landings to countries in proportion to their reported landings in the area (see also Rossing *et al.* 2010a; Zeller *et al.* 2011). Many of the stock assessments begin estimating these unreported catches in the 1980s and 1990s. A rate of unreported catch is determined for each taxon in the first year of available unreported data in the stock assessment reports. For 1950, a rate of 5% is assumed and applied to reported landings (see also Rossing *et al.* 2010b). Rates are interpolated for each taxon between the 5% in 1950 and the first available rate from the stock assessments (Table 1). However, if the specific taxon's rate of unreported landings from the stock assessment is below 5%, that rate is carried back to 1950.

Table 1. Anchor points used to estimate unreported landings of commercially important taxa in Germany based on ICES stock assessments 1950-2010.

Taxon	Assumed 1950 percentage of unreported landings	First year with available data from stock assessments	Percentage of unreported landings in first year from stock assessment
European plaice	5.0	1980	27.2
Common sole	0.5	1982	0.5
Saithe	3.6	1990	3.6
Whiting	1.4	1993	1.4
Haddock	5.0	1992	27.6
Atlantic cod	5.0	1993	9.7
Atlantic mackerel	5.0	1986	8.3
Altantic horse mackerel	1.3	1994	1.3
Atlantic herring	5.0	2002	7.0

Brown shrimp (*Crangon crangon*) are a special case and therefore are being treated separately here. Before 1970, substantial by-catch of fish and undersized shrimp was landed and used as chicken feed, duck feed or fertilizer (Berghahn and Purps 1998; T. Neudecker, pers. comm. Johann Heinrich von Thünen-Institut). Brown shrimp by-catch values and composition from Ulleweit *et al.* (2010) are used to calculate discard tonnages over the time series (see discard methods). Unreported landings from the brown shrimp fishery are taken from the estimated by-catch. Due to on-deck sieving techniques in this fishery, it is estimated that 50% of by-catch of shrimp (but not other invertebrates, see 'general discards' below) from 1950-1965 would have been landed but remained unreported, the remaining 50% would have been discarded at sea (ICES 2012d). From 1966-1970, the amount of unreported landed by-catch is decreased by 10% each year, until in 1970, 0% of the by-catch is landed and 100% is discarded. All fish by-catch is unreported from 1950-1965, and decreases by 20% each year until there is 0% landed and 100% discarding in 1970.

High-grading

Evidence for high-grading, or 'slipping' as ICES terms it (essentially a discarding of marketable catches for profit maximization), was documented for the Atlantic mackerel fishery (ICES 2012c) but is likely to also occur in other fisheries. Prior to 1994, Atlantic mackerel were high-graded in order to meet demands of the Japanese market for fish larger than 600 g (ICES 2012c). There are higher estimated discards from the ICES stock assessment in 1988,

relative to those from 1989-2010. In order to determine a high-grading rate, the difference in discards in 1988 and 1989 is divided by the total catch for 1988 and converted into a rate (0.226 t of mackerel discarded as a result of high-grading per 1 t landed in 1988). This rate is carried forward to 1994 and then interpolated to a high-grading rate of zero in 1996 as well as 1980. The calculated rates are applied to total landings for the years 1981-1995. Discards in the form of high-grading supplement the ICES WGWIDE report estimates of discards (ICES 2012c).

General discards

Discards for the German North Sea fisheries vary greatly, based on target species and gear type. Discards are determined individually for Germany's larger fisheries. These larger fisheries are for Atlantic mackerel (*Scomber scombrus*), European plaice (*Pleuronectes platessa*), common sole (*Solea solea*), saithe (*Pollachius virens*), Atlantic herring (*Clupea harengus*), whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*), Atlantic cod (*Gadus morhua*) and brown shrimp (*Crangon crangon*). These fisheries make up a large portion of Germany's national landings from within their EEZ equivalent waters (Figure 3). The general method is to determine an average discard rate and apply it to landings in time periods with no specific discard information for each of these fisheries.

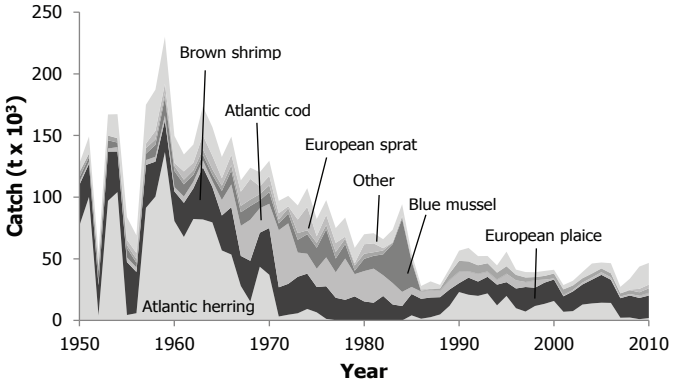

Figure 3. Germany's reported landings of major targeted taxa within their EEZ.

For Atlantic mackerel (see also high-grading above), whiting, Atlantic herring and haddock, discard data are taken from respective ICES working group reports (ICES 2012a, 2012b, 2012c, 2012d). These data are only for discards of the target species within the species-specific fishery, for example, haddock discards in the haddock targeted fisheries. Thus, the present discard data represent minimal discards. A discard rate is determined for the earliest year of available data, or in some cases (if highly variable) the average of the earliest two or three years of available discard data. This rate is applied to the reported landed tonnages to determine a tonnage of discards for time periods with missing information. In the case of European plaice, common sole, saithe, Atlantic cod and brown shrimp fisheries, a study of the German North Sea fisheries' discards is used (Ulleweit *et al.* 2010). This is an observational study presenting data in the form of discards of an average trip from 2002-2008. An average discard rate is determined for each target species for this time period and applied to reported landings for years with missing discard data. These discard values are then distributed proportionally among the catch composition for the target fisheries present in Ulleweit *et al.* (2010). It is feasible that discard practices differed in earlier periods, but we have no information on this, hence we retained a consistent pattern over time. Overall, the discards estimated here are minimal estimates of overall discards, as they often exclude discards of non-target taxa (see Table 2).

Table 2. Discard rates applied to missing time periods for major taxa for the German North Sea fisheries.

Target species	Discard taxa	Discard rate (%)	Time applied	Source
Brown shrimp	All taxa[1]	172	1950-2010	Ulleweit *et al.* (2010)
Brown shrimp	Sole	1	1950-1978	Tiews (1980)
Brown shrimp	Cod	4	1950-1978	Tiews (1980)
Atlantic mackerel	Mackerel	13	1950-1985	ICES (2002b, 2012c)
European plaice	All taxa	208	1950-2010	Ulleweit *et al.* (2010)
Common sole	All taxa	226	1950-2010	Ulleweit *et al.* (2010)
Saithe	All taxa	<1	1950-2010	Ulleweit *et al.* (2010)
Atlantic herring	Herring	<1	1950-1992	ICES (2003, 2012a)
Whiting	Whiting	78	1950-1991	ICES (2002a, 2012b)
Haddock	Haddock	90	1950-1991	ICES (2002a, 2012b)
Atlantic cod	All taxa	3[2]	1950-2010	Ulleweit *et al.* (2010)

[1] This taxonomic composition does not include sole and cod

[2] This value represents discarded taxa from a smaller fishery targeting cod, and is used here as a conservative minimal estimate as other data were not accessible.

Brown shrimp is again treated as a special case due to the unreported by-catch from 1950-1970, as outlined in the previous section. The 50% of by-catch that is not used as unreported landed by-catch was deemed to have been discarded at sea from 1950-1965. From 1966-1970, the amount of discarded by-catch was increased by 10% each year, until in 1970, 100% of the by-catch was discarded and 0% was landed. For the entire time series, 100% of invertebrates, other than shrimp, were deemed to be discarded. No fish by-catch was retained after 1970, so these values were designated to discards from 1970-2010. In the brown shrimp fishery, there are a series of sieving processes for retaining the right sized shrimp suitable for marketing. The first sieving is immediately after hauling the catch and everything undersized is immediately discarded (ICES 2012d). The shrimp is then cooked and sieved for a second time and all undersized shrimp are again discarded (ICES 2012d). A final, third sieving is done on land, and the undersized shrimp are used for industrial purposes and recorded as separate landings (ICES 2012d).

In the case of the brown shrimp fishery, there is additional data available that provides more precise amounts of discards for some taxa in the earlier part of the time series. Purps and Damm (2001) provide numbers of European plaice discards from 1954-1988. The numbers of European plaice were converted to mass using the FishBase length-weight conversion function. These numbers are used in place of the estimated plaice discards in the brown shrimp fishery from Ulleweit *et al.* (2010). Other proportions of discarded taxa in this fishery are normalized for this time period in order to account for changed plaice discards. Values for undersized common sole and Atlantic cod discards in the brown shrimp fishery from Tiews (1980) are included in 1978. A discard rate is determined for these taxa and carried back to 1950. The discards for common sole and Atlantic cod are set at 0 t in 2001 and the discard rate is interpolated between 1978 and 2001.

Recreational/subsistence catches

Recreational fishing in the German North Sea is poorly documented, and generally of low importance. For the more significant German recreational fisheries in the Baltic Sea, see Rossing *et al.* (2010b). It is difficult to estimate how many recreational North Sea fishers there are based on recreational licensing procedures. Much of the information acquired for this reconstruction is personal communication with other researchers and fishers. Recreational fishing in the North Sea in recent times is essentially limited to charter boats, making their catches a useful proxy for annual German recreational catch estimates.

Table 3. Anchor points to estimate German recreational catches from 1950-2010 in the North Sea. Dashed lines (-) indicate years when linear interpolations were used.

	Taxon (tonnes)						Sharks (numbers)			
Year	European eel	Atlantic cod	Mackerel	Mussels	Misc. molluscs	Sea bass	Tope shark	Picked dogfish	Small spotted catshark	Smooth hound
1950	40	0	0.15	177.5	177.5	0	120	80	60	60
1960	-	-	-	-	-	0	120	40	30	30
1970	-	-	-	-	-	0	100	40	30	30
1990	-	40	-	-	-	0	-	-	-	-
1995	-	-	4.50	-	-	0	-	-	-	-
1999	-	40	-	-	-	0	-	-	-	-
2000	-	35	-	-	-	0	-	-	-	-
2010	1	30	3.00	5.0	5.0	5	20	72	54	54

The more historical recreational fisheries were for European eel (*Anguilla anguilla*), blue mussels and other marine molluscs. In the early years, a proportion of these fisheries likely had more a 'subsistence' or 'supplementary subsistence' nature (i.e., feeding one's family) rather than a pure recreational purpose (i.e., pleasure as the major driver). More recent recreational fisheries are for Atlantic cod, Atlantic mackerel, Tope sharks (*Galeorhinus galeus*), and European sea bass (*Dicentrarchus labrax*). A government survey of recreational Atlantic cod catches in the North Sea, based on a pilot study in 2004-2006 estimated an annual catch of 30 t (Anon. 2007, 2011). Data for other recreational species are not readily available. We derive assumed anchor points using qualitative information acquired by personal communication (Table 3). Anchor points for recreational fisheries are based on Anon. (2011), H. Strehlow (pers. comm., Johann Heinrich von Thünen-Institut) and M. Janke (pers. comm., fisher). Shark values are number of individuals and the other species are estimated tonnages.

Non-commercial fishing with a larger emphasis on sustenance (i.e., subsistence) rather than recreational pleasure for European eel, blue mussel and miscellaneous molluscs was more common in earlier time periods (H. Strehlow, pers. comm., Johann Heinrich von Thünen-Institut). The 1950 anchor point for all non-commercially fished molluscs was arbitrarily estimated at 10% of the commercial blue mussel catch from 1950. This value was then split equally between Blue mussels and miscellaneous molluscs. Miscellaneous molluscs include species such as the surf clam (*Spisula subtruncata*), the American razor clam (*Enis directus*), common edible cockle (*Cerastoderma edule*), and since 1990, the introduced Pacific oyster (*Crassostrea gigas*) (Lotze 2007; H. Strehlow, pers. comm., Johann-Heinrich von Thünen Institut). Thus, after estimating total non-commercial catch time series for eel, blue mussel and misc. molluscs, we split these into assumed subsistence and assumed recreational components equally.

Total catches

Reconstructed total catches are assembled by combining reported landings, unreported catches (commercial, recreational and subsistence) and discards. Data are presented by taxon as well as by major fisheries sectors as defined globally by *Sea Around Us*, these being: industrial (i.e., large-scale, commercial), artisanal (i.e., small-scale, commercial), subsistence and recreational, plus discards. We assign commercial catches (reported, unreported and discards) to the large-scale and small-scale sectors as follows. The small-scale sector applies to the inshore blue mussel fishery. In 1950, we allocate 60% of these catches to the small-scale sector and 40% to the large-scale sector. In 2010, we allocate 10% of these catches to the small-scale sector and 90% to the large-scale sector. Fisheries that target deeper water species or use a dragged bottom gear type are defined entirely as large-scale fisheries. For the time between 1950 and 2010, we interpolate the sector proportions and then apply them to the reconstructed catches for each year.

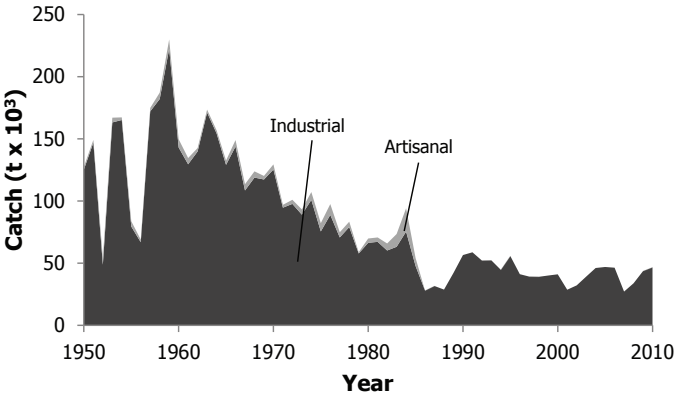

Figure 4. Total reported ICES landings for Germany subdivision IV b, 1950-2010, segregated into large-scale commercial (i.e., industrial) and small-scale commercial (i.e., artisanal) sectors based on taxon-specific assumptions.

Results

Landings data

The total reported landings, combining former West, East and reunified Germany, for ICES sub-division IV b from 1950-2010 is 5.2 million t (Figure 4). Reported landings increased with substantial inter-annual variation from 127,000 t in 1950 to a peak of 230,000 t in 1959, before declining to 46,700 t by 2010 (Figure 4). Using our assumed fisheries sector split, the total reported industrial landings from 1950-2010 are just over 5 million t, i.e., 97% of total reported landings (Figure 4). This tonnage includes all groups reported to ICES. Reported artisanal landings totaled 172,000 t from 1950-2010. Note, there were adjustments made to some of the major taxa, based on over-reporting in some years for some species (Table 4).

Table 4. Total adjustments (tonnes) made to ICES landings data for Germany 1950-2010, based on ICES (2002a, 2002b, 2003, 2012a, 2012b, 2012c)

Target species	1980-1989	1990-1999	2000-2009	2010
Herring	-	-8868	-4743	-
Horse mackerel	-	-194	-306	-
Mackerel	-	-<1	-<1	-
Cod	-	-50	-308	-25
Haddock	-	-43	-13	-
Whiting	-	-7	-52	-
Saithe	-<1	-	-175	-
Sole	-	-	-22	-
Plaice	-	-1	-49	-

Illegal, Unreported and Unregulated (IUU) catches

Catches that are not publically reported by flag country, area, taxon and year through the electronic ICES landings statistics are here considered to fall under the general if poorly defined 'Illegal, Unreported or Unregulated' (IUU) term. The components of IUU estimated here are: a) unreported landings; b) high-grading; c) general discards; d) recreational; and e) subsistence catches.

Unreported catches

Unreported catches total over 522,000 t from 1950-2010 (Figure 5). Unreported catches vary greatly, both between taxa and over time. In the period from 1950-1970, there were substantial unreported landings from the brown shrimp fishery that were used for livestock feed and fertilizer (T. Neudecker, pers. comm. Johann Heinrich von Thünen-Institut). Thus, brown shrimp, common dab (*Limanda limanda*), European plaice, whiting, Atlantic herring, sand eels, hook nose (*Agonus cataphractus*), sand goby (*Pomatoschisus miustus*), Atlantic cod and common sole are all included in unreported landings from the brown shrimp fishery. In 1950, approximately 31,000 t·year^{-1} of fish and shrimp were landed but not reported. Most of this catch is due to the landing of fish for livestock feed and fertilizer. These unreported landings peaked at 41,000 t·year^{-1} in 1963 and declined to 810 t·year^{-1} in 2010. Other unreported taxa derived from ICES stock assessments are Atlantic herring, common sole, European plaice, saithe, whiting, haddock, Atlantic cod, Atlantic horse mackerel and Atlantic mackerel. Many smaller vessels (under 12m of length) are suspected of likely not reporting a large fraction of their undersized by-catch from shallow nursery areas in the Baltic Sea (R. Froese pers. obs.), and this may also apply to the North Sea. We could not find any information on any such unreported catches, and more attention is needed for comprehensive monitoring and accounting of catches from smaller fishing vessels.

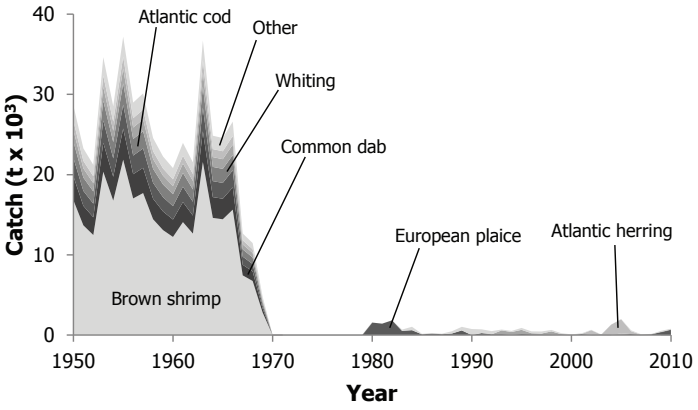

Figure 5. Unreported landings in Germany from 1950-2010, as estimated here.

High-grading

High-grading is found to occur at least in the Atlantic mackerel fishery during the 1980s to the mid-1990s (ICES 2012c). Based on ICES source material, high-grading in this fishery was found to have removed 96 t of Atlantic mackerel from 1981-1995 in addition to the reported ICES landings.

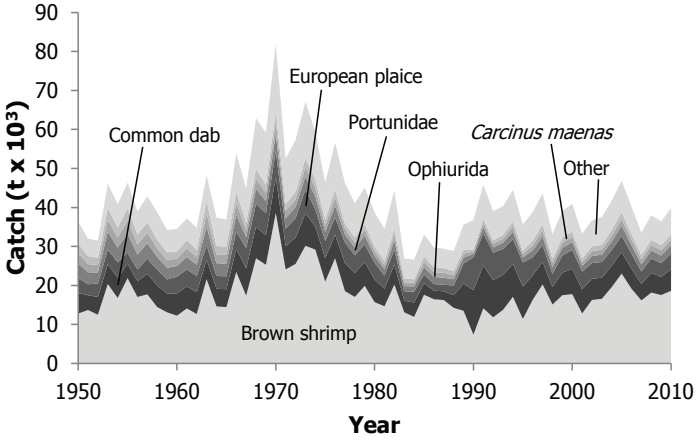

Figure 6. Germany's discards in its North Sea EEZ by major taxa, 1950-2010.

General discards

Total general discards for all species from 1950-2010 are estimated at slightly over 2.6 million t (Figure 6). Discards are consistently substantial throughout the time series, from over 43,000 t·year^{-1} in 1950 to a peak of 84,000 t·year^{-1} in 1970. By 2010, discarded by-catch is approximately 40,000 t·year^{-1}, which is nearly equivalent to the discards in 1950. Discards of undersized brown shrimp average over 17,800 t·year^{-1} and make up approximately 43% of the total discards (Figure 6). Common dab makes up 14% of the discards and European plaice represents 10%. Portunidae, Ophiurida and *Carcinus maenas* represent 6%, 4% and 4%, respectively, of total discards. The 'other' category is comprised of 42 invertebrate and fish species and makes up approximately 22% of total discards. The highest discards are seen in the brown shrimp fisheries. The top six discarded groups are all common by-catch in the brown shrimp bottom trawl fishery (Ulleweit *et al.* 2010).

Recreational catches

Our approximate estimates of recreational catches total nearly 8,000 t from 1950-2010, and decline steadily over time, from approximately 200 t·year^{-1} in 1950 to 43 t·year^{-1} by 2010. While small in tonnage compared to commercial catches, our study makes this the first time-series estimate for German recreational fishing in the North Sea. These catches include blue mussels, miscellaneous molluscs, Atlantic cod, European eel, Atlantic mackerel, various sharks and European sea bass.

Blue mussel and miscellaneous molluscs total around 2,800 t each and make up approximately 35% of the total recreational catches each. It is possible that this is an over-representation of molluscs in recreational catches. European eel makes up approximately 8% of the total catch, most of which was likely caught in earlier time periods. Miscellaneous sharks include tope shark (*Galeorhinus galeus*), picked dogfish (*Squalus acanthias*), smooth hound (*Mustelus mustelus*) and small spotted catshark (*Scyliorhinus canicula*) (M. Janke, pers. comm., fisher). Shark catches represent less than 1% of total recreational catches. All of these groups demonstrate a declining trend over time. However, recreational fisheries for Atlantic mackerel (2% of total catch), Atlantic cod (19% of total catch) and European sea bass (less than 1% of total catch) demonstrate a general increase in catches over time.

Subsistence catches

Our approximation of subsistence catches (main driver is self- or family-consumption rather than pleasure) total approximately 6,000 t from 1950-2010, and demonstrate a strongly declining trend, from almost 200 t·year^{-1} in 1950 to 6 t·year^{-1} by 2010). Subsistence catches were assumed to consist of collected blue mussels and other molluscs, and European eel.

Reconstructed total catches

The reconstructed total catch for Germany in their North Sea EEZ equivalent waters, including adjustments, and estimates of unreported landings, discards, and recreational and subsistence catches is estimated at slightly under 8.3 million t for 1950-2010. This is 59% higher than the officially reported ICES landings of just over 5.2 million t (Figure 7a). The reconstructed total catch follows the same general time trend as the reported landings. The reconstruction of invertebrate catches was more substantial than that of fish species. The reported invertebrate landings totals just over 1.9 million t and the reconstructed catch is over 3.8 million t, which is a 97% increase. Fish species, however, only have an increase of 37% from 3.2 million t reported to 4.5 million t reconstructed. Overall, discards accounted for the majority (31%) of the unreported component of the reconstructed total catches (Figure 7a). Taxonomically, brown shrimp accounted for the largest share of the reconstruction, accounting for 33% (i.e., almost 273,000 t) of reconstructed total catches (Figure 7b). The next largest contributors were Atlantic herring, Atlantic Cod and European plaice with 21%, 8% and 7%, respectively (Figure 7b). Note the declining contributions of herring and cod, and the generally increasing contribution of plaice over the time period considered here (Figure 7b).

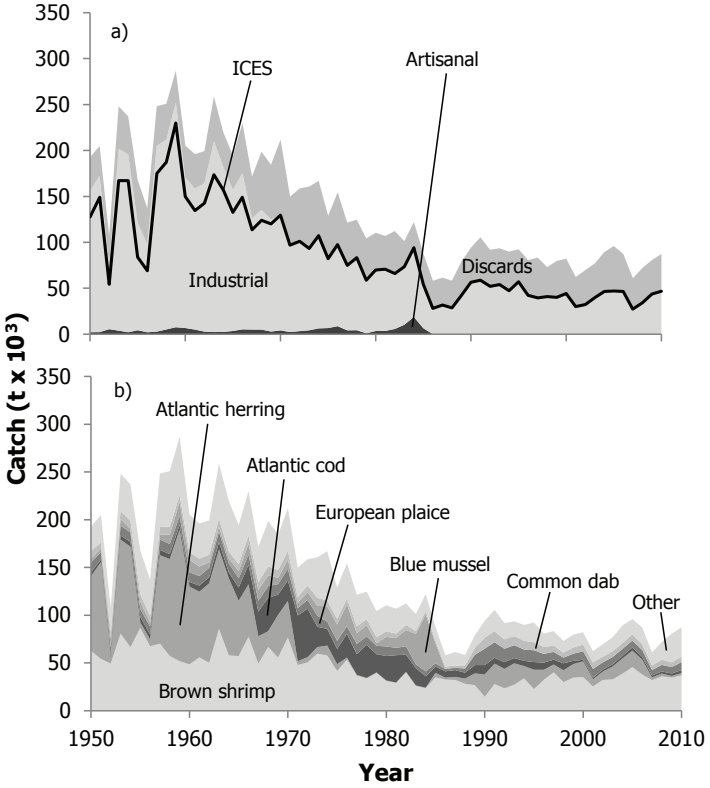

Figure 7. Germany's total reconstructed catch for 1950-2010, by a) fishing sectors plus discards for 1950-2010. Note that the official ICES data are overlaid as a line graph and b) major taxa.

Discussion

The reconstructed total catch for Germany in its North Sea EEZ equivalent waters from 1950-2010 is approximately 8.5 million t, which is 63% higher than the official reported data of 5.2 million t. Major contributors to missing data are discards (entire time period) and unreported landings (mainly earlier decades), while recreational and subsistence catches contribute minor amounts.

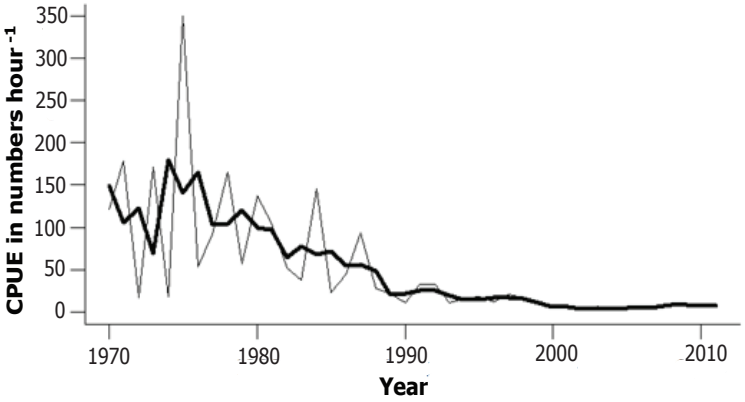

Figure 8. Numbers of North Sea cod caught in one hour of research trawling in the German Bight. The bold line represents a moving average. While about 150 cod were caught in the 1970s, only 2-3 cod were caught after 2000. Source- http://datras.ices.dk.

During the period 1950-2010, German catches have been collected by three different bodies of government (Kaschner *et al.* 2001). From 1924-1980, the Bundesfischereiforschungsanstalt (Federal Research Institute for Fisheries) reported catches, followed by the Statistische Bundesamt (Federal Statistical Office) from 1980 to 1990 (Kaschner *et al.* 2001). After reunification in 1990, the Bundesministerium für Landwirtschaft, Ernährung und Forsten (Federal Ministry for Agriculture, Food and Forestry) began to report catches (Kaschner *et al.* 2001). The passing of responsibility from one government body to the next over time likely makes room for discrepancy amongst taxonomic designations. The taxonomic grouping in East Germany and West Germany were more general with many more 'miscellaneous' groups reported in less specific management areas. After reunification, taxonomic grouping is mostly to species level and there are fewer 'miscellaneous' categories with more specific management area designations.

Discards are of large concern for all fisheries, even with gear restrictions and improvement in technology (Kelleher 2005). For Germany's North Sea fisheries, we estimate discards to represent 31% of the total catch, with brown shrimp being the highest discarded taxon (40%). Unreported landings are also of concern. Our estimates of unreported landings represent over 7% of the total reconstruction, and once again brown shrimp makes up the largest portion (42%).

Our estimates of discards are based on recently published surveys and ICES working groups (ICES 2002a, 2002b, 2003; Ulleweit *et al.* 2010; ICES 2012a, 2012b, 2012c). Discard rates are determined and then proportionally applied to ICES landings statistics. We believe that our estimates of discards remain conservative. Discard values are not available for all species present in the working groups. When the ICES discard estimates are present, they are often for all of sub-area IV and not separated into the sub-divisions IV a, IV b and IV c. For example, the Atlantic cod stock assessment for sub-area IV includes unreported values but no discards (ICES 2002a, 2012b). If ICES would provide discard estimates for all of the stock assessments in their working group reports, the discards would be more inclusive and accurate.

There is likely further underestimation for the brown shrimp fisheries. Discard data for this fishery are estimated using observational sampling on German vessels as part of the EU fisheries data collection programme, however there are only data from 2002-2008 (Ulleweit *et al.* 2010). The discard rate derived from the data is applied proportionally to ICES landings statistics for the period 1950-2010. Before 1970, all fish by-catch and much of the shrimp by-catch were landed and used for local duck feed or fertilizer and these by-catch landings were unreported (Tiews 1980; Berghahn and Purps 1998; T. Neudecker, pers. comm., Johann-Heinrich von Thünen Institut). This suggests that our estimate of discards and unreported landings for the brown shrimp fishery could be under-estimates. Overall, discards decrease over the last 20 years but mainly as a result of lower landings and our methods. While the EU has a data collection programme for discards, more needs to be done for the beam trawl fisheries targeting brown shrimp and flatfish (Berghahn and Purps 1998; Neudecker and Damm 2010; Ulleweit *et al.* 2010). Discards in these fisheries are high and should be reduced. Overall, discards should be estimated rigorously for all taxa discarded, and should become part of public reporting systems.

A remarkable development is the collapse of the German cod fishery due to the disappearance of the species from the southern North Sea (Figure 8). The most likely cause is continuous severe overfishing at three times the sustainable rate, which started in 1970 and is still ongoing (Froese and Quaas 2012; ICES 2012b).

Unreported landings, also called 'unallocated' landings by ICES, are a cause of concern. These data are likely minimal estimates, and the inability or political unwillingness to comprehensively account for such catches by flag-country points to a deep-seated problem of lack of transparency and accountability in European fisheries data (Zeller *et al.* 2011). Our reconstruction of German fisheries in the North Sea EEZ from 1950-2010 demonstrates that there are significant catches (both unreported landings and discards) that are not being reported or publically available through ICES landings statistics.

Acknowledgements

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Appendix Table A1. ICES vs. reconstructed total catch (in tonnes), and catch by sector with discards shown separately, for Germany, 1950-2010.

Year	ICES	Reconstructed total catch	Industrial	Artisanal	Subsistence	Recreational	Discard
1950	127,508	192,900	154,000	2,132	198	199	36,400
1951	149,173	204,800	170,200	2,200	194	197	32,000
1952	54,272	107,400	70,000	5,476	191	195	31,500
1953	167,052	248,100	197,900	3,828	188	193	46,100
1954	167,289	237,100	193,700	2,096	185	191	40,900
1955	83,799	167,700	116,700	4,273	182	189	46,400
1956	68,988	137,300	95,900	2,070	178	186	38,900
1957	174,925	248,200	202,300	2,783	175	184	42,800
1958	187,177	250,800	206,600	5,145	172	182	38,700
1959	229,971	286,800	244,700	7,567	169	180	34,200
1960	149,743	205,400	163,900	6,692	166	178	34,500
1961	134,596	196,100	153,500	5,026	162	176	37,200
1962	142,668	199,300	161,400	2,776	159	174	34,700
1963	173,526	258,700	207,900	2,302	156	172	48,200
1964	156,919	219,500	179,300	2,442	153	170	37,400
1965	132,579	194,300	153,700	3,481	150	167	36,900
1966	149,059	229,800	170,400	5,248	146	165	53,900
1967	113,582	171,500	121,200	5,054	143	163	45,000
1968	123,890	198,500	130,300	5,024	140	161	62,900
1969	120,198	184,400	122,100	2,852	137	159	59,200
1970	129,490	211,800	125,400	4,123	134	157	82,000
1971	96,971	149,800	94,700	2,300	130	155	52,600
1972	101,029	158,600	97,700	3,306	127	153	57,300
1973	93,300	160,700	89,100	4,222	124	150	67,100
1974	107,251	166,900	100,900	6,316	121	148	59,400
1975	82,225	128,900	75,600	6,649	118	146	46,400
1976	97,584	154,400	88,900	8,695	114	144	56,600
1977	74,922	121,400	70,700	4,181	111	142	46,300
1978	83,401	124,700	79,100	4,307	108	140	41,000
1979	58,855	104,200	57,900	990	105	138	45,100
1980	69,893	110,400	68,000	3,470	102	136	38,700
1981	70,741	106,900	68,600	3,544	98	133	34,500
1982	65,898	112,300	62,100	5,650	95	131	44,300
1983	73,506	101,300	63,900	10,277	92	129	26,900
1984	94,231	122,100	76,500	18,782	89	127	26,600
1985	54,201	87,600	47,900	6,419	86	125	33,100
1986	27,967	58,100	28,200	-	82	123	29,700
1987	31,668	61,400	31,800	-	79	121	29,400
1988	28,820	58,300	29,300	-	76	119	28,800
1989	42,224	79,100	43,200	-	73	116	35,600
1990	56,594	94,300	57,300	-	70	114	36,700
1991	58,800	105,500	59,500	-	66	111	45,800
1992	52,165	91,900	52,700	-	63	108	39,000
1993	52,298	93,500	53,000	-	60	105	40,300
1994	44,663	89,800	45,200	-	57	102	44,500
1995	55,747	92,400	56,600	-	54	99	35,600
1996	41,217	80,600	41,700	24	50	95	38,800
1997	39,250	83,400	39,700	-	47	92	43,600
1998	39,098	73,000	39,700	-	44	89	33,100
1999	40,130	79,700	40,400	-	41	85	39,200
2000	41,096	82,200	41,200	-	38	77	40,900
2001	28,709	62,200	28,900	-	34	69	33,200
2002	32,194	69,600	32,800	-	31	67	36,700
2003	39,241	76,900	39,300	-	28	64	37,500
2004	46,173	89,300	47,500	-	25	61	41,800
2005	46,990	95,900	49,000	-	22	58	46,800
2006	46,421	87,300	47,000	-	18	55	40,200
2007	27,217	60,900	27,300	-	15	52	33,500
2008	33,865	72,000	34,000	-	12	50	38,000
2009	43,677	80,700	44,200	-	9	47	36,400
2010	46,651	87,300	47,400	-	6	44	39,800

Appendix Table A1. Reconstructed total catch (in tonnes) by major taxa, for Germany, 1950-2010. 'Others' contain 116 additional taxonomic categories.

Year	*Crangon crangon*	*Clupea harengus*	*Gadus morhua*	*Pleuronectes platessa*	*Mytilus edulis*	*Limanda limanda*	Others
1950	62,600	78,383	3,920	10,390	3,732	8,330	25,600
1951	54,200	101,213	2,840	7,610	3,894	6,340	28,700
1952	49,400	4,952	3,060	8,520	9,559	6,870	25,000
1953	80,700	98,492	4,270	10,350	6,826	8,720	38,800
1954	66,400	105,366	5,050	9,780	3,865	8,260	38,300
1955	86,600	5,930	5,650	8,310	7,816	7,690	45,700
1956	67,500	7,045	5,180	8,390	3,923	7,160	38,100
1957	70,100	92,648	5,550	10,830	5,295	8,490	55,300
1958	57,200	101,535	5,250	10,520	9,801	8,160	58,300
1959	51,800	137,580	5,220	9,220	14,566	7,280	61,100
1960	48,500	81,572	4,740	10,070	13,101	7,960	39,500
1961	55,800	68,748	6,450	10,000	10,034	8,260	36,800
1962	50,100	83,241	6,590	9,690	5,695	7,870	36,100
1963	85,500	83,482	7,500	11,070	4,823	8,880	57,500
1964	57,900	80,631	6,280	9,620	5,190	7,180	52,700
1965	57,200	57,838	13,960	9,590	7,462	7,210	41,100
1966	77,400	54,865	20,390	10,830	11,378	8,780	46,100
1967	49,100	28,875	25,750	11,390	11,156	8,430	36,800
1968	66,800	16,449	35,170	12,110	11,291	9,300	47,500
1969	55,700	44,581	21,300	11,000	6,581	8,150	37,200
1970	76,500	38,428	21,550	12,220	9,634	9,200	44,300
1971	47,800	4,043	47,890	7,730	5,529	6,040	30,800
1972	50,500	5,529	50,730	9,240	8,048	6,810	27,700
1973	59,700	6,868	21,190	11,570	10,451	8,380	42,500
1974	57,800	10,316	17,580	7,610	15,899	5,990	51,700
1975	41,500	7,298	15,890	8,420	17,081	6,060	32,600
1976	53,400	2,197	24,880	7,990	22,786	6,110	37,100
1977	36,700	857	21,720	10,640	11,250	7,280	33,000
1978	33,800	584	34,660	8,800	11,843	6,230	28,800
1979	39,400	681	19,120	8,750	2,856	6,210	27,200
1980	31,100	540	25,630	9,980	10,005	5,840	27,300
1981	29,000	502	28,630	7,660	10,462	4,540	26,100
1982	40,000	709	17,910	8,820	17,036	5,210	22,500
1983	26,000	547	18,180	4,010	31,706	3,020	17,900
1984	23,600	410	12,150	5,110	59,390	3,730	17,700
1985	34,900	4,747	6,610	3,400	20,895	2,960	14,100
1986	32,600	1,974	6,670	2,480	74	2,250	12,100
1987	32,200	3,221	7,140	2,390	71	2,270	14,200
1988	28,200	5,376	6,200	4,260	68	3,340	10,800
1989	26,700	12,355	8,740	10,780	65	7,130	13,300
1990	14,600	23,304	9,860	17,180	63	11,640	17,600
1991	28,000	21,360	6,050	16,340	60	11,410	22,300
1992	23,400	20,380	7,080	13,970	57	9,790	17,200
1993	27,200	22,411	5,560	13,410	54	9,470	15,400
1994	33,800	12,887	5,460	11,830	51	9,040	16,700
1995	22,600	20,329	8,050	12,350	48	8,330	20,700
1996	32,300	10,553	7,520	9,120	155	7,010	14,000
1997	40,100	8,183	5,150	8,030	42	6,710	15,100
1998	29,900	12,436	7,270	5,960	40	5,240	12,100
1999	34,600	14,225	3,330	7,480	37	6,510	13,400
2000	35,100	16,469	1,710	8,850	34	7,070	12,900
2001	25,400	7,497	1,790	9,140	31	6,780	11,700
2002	32,200	8,739	2,040	7,620	28	5,930	13,100
2003	32,800	13,497	2,290	7,610	25	5,990	14,700
2004	38,800	15,964	2,670	7,340	22	6,130	18,400
2005	45,600	17,273	3,280	7,260	19	6,550	15,900
2006	37,900	15,572	2,870	7,210	17	6,180	17,500
2007	32,000	2,803	2,100	5,730	14	4,740	13,500
2008	36,000	3,000	2,080	6,880	11	5,380	18,700
2009	34,700	1,658	2,590	6,670	8	4,930	30,100
2010	36,900	2,546	3,110	8,320	5	5,830	30,600