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Abstract

We reconstruct the total Danish marine fisheries catch within the Kattegat, Skagerrak and North Sea Exclusive Economic Zone (EEZ) equivalent waters from 1950-2010. We use publically available electronic landings data from the International Council for the Exploration of the Seas (ICES) as a 'reporting' baseline for our reconstruction. This baseline is then improved upon using all data accessible to us, including ICES stock assessments, peer-reviewed literature, grey literature and local expert opinions. Illegal, Unreported and Unregulated (IUU) catches are assessed in the form of unreported catch, over-reported catch, discarded by-catch, as well as recreational and subsistence catches. The reconstructed total catch from 1950-2010 was estimated at 55 million t, which is 1.09 times greater than the reported landings of 50 million t. Sandeels (*Ammodytes* spp.) comprise the largest amount of reported baseline landings from 1950-2010 due to its importance in the Danish industrial reduction fisheries. The largest contribution to the unreported component is discarded by-catch. Our estimates suggest that whiting (*Merlangius merlangus*) is the most discarded species over the time series considered. The discrepancy between the reported landed catch and the reconstructed total catch is mostly due to discarded by-catch that is not officially reported by ICES in their public electronic catch database.

Introduction

Denmark is a member of the European Union (EU) with an area of 43,075 km², and a coastline that borders the Baltic, Kattegat, Skagerrak and North Seas. The country consists of Jutland, a larger, less populous land mass attached to the main continent of Europe, and islands throughout the Kattegat and Baltic Seas. There is no Danish resident living more than 50 km from the coast (Sparrevohn and Storr-Paulsen 2012b), and as a result, there is a strong maritime culture and a rich fisheries history. In the early 20th century, 71% of fishers had parents that fished and 75% had not moved from their place of birth (Vestergaard 1990). Challenges with over-exploited stocks have led to a decline in the number of fishers and a reduced feeling of importance amongst fishers (Vestergaard 1990). Despite this decline, the fishing industry in Denmark is still quite large relative to the size of the country (Storr-Paulsen *et al.* 2010).

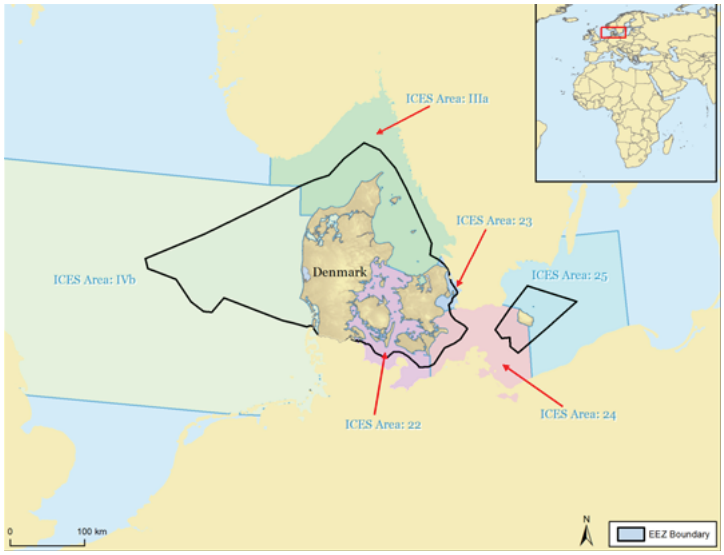

Figure 1. Denmark's EEZ and corresponding ICES management areas.

As a result of Denmark's association with the EU, the Danish management system is multi-faceted, considering the period before and beyond joining the EU. Catch quotas were agreed upon beginning in the mid-1970s through the North-East Atlantic Fisheries Commission (NEAFC) (Daan 1997). Denmark joined the EU in 1973[1] and soon after in 1977, with the creation of Exclusive Economic Zones (EEZs), NEAFC lost its mandate (Daan 1997). The EU assumed full control of EEZ waters (Daan 1997) and by 1983 the EU's Common Fisheries Policy (CFP) began creating Total Allowable Catches (TAC) (Nielsen 1989). TACs are created based on the status of each stock and are then divided amongst EU countries (Nielsen 1989), while considering historical fishing rights. Since January 1, 2007 the Danish DTU Aqua – National Institute of Aquatic Resources is independently responsible for all aquatic research and is often involved with status reports and policy making. Prior to this date, DTU Aqua was a sector within the Danish Ministry of Food, Agriculture and Fishery (MFAF). The MFAF has the right to allocate the Danish quota share through licensing of Danish fisheries (Nielsen and Christensen 2006), even though they are not responsible for setting TACs.

[1] http://europa.eu/about-eu/countries/member-countries/denmark/index_en.htm (accessed October 2, 2013)

There are four main divisions within Danish fisheries: mixed demersal, mixed pelagic, industrial-reduction and invertebrate (mussels and shrimp) fisheries (Nielsen and Christensen 2006). Danish fishers act as individuals that may change their strategies and effort, within standard gear restrictions, as they wish to fill specific quotas (Nielsen and Christensen 2006). In the Kattegat and Skagerrak Norway lobster (*Nephrops norvegicus*) fishery, European plaice (*Pleuronectes platessa*), Atlantic cod (*Gadus morhua*), witch flounder (*Glyptocephalus cynoglossus*) and haddock (*Melanogrammus aeglefinus*) may also comprise large amounts of the landed catch (Catchpole and Revill 2008; Frandsen 2010). In the North Sea shrimp fishery, fishers may also catch flat fish species and then change to trawling for sandeel (*Ammodytes* spp.) when the shrimp quota is filled (Aviat *et al.* 2011). The industrial reduction fishery (mainly for sandeel, but also for herring) has been the largest sector in Denmark since the 1960s (Byskov 2013). The first plant for reduction of fish into fish meal and fish oil was built in Esbjerg in 1948 (Byskov 2013). These reduction products have been used for aquaculture feed, agriculture, live-stock feed and margarine (Macer and Burd 1970; Feekings *et al.* 2012). Throughout the middle of the 20th century, the reduction fisheries were being subsidized by the government to enhance vessels and equipment (Byskov 2013), which is followed by an increase in catch. Sandeel catches experienced a three year low from 2003-2005 (Byskov 2013) and these declines follow the trend within this fishery. No new industrial vessels have been built or introduced into the fishery in the last 25 years, and by 2008, the plant in Esbjerg was closed (Byskov 2013).

The mixed fisheries of Denmark also make large contributions to commercial landings and they create the most complex of discard problems (Feekings *et al.* 2012). Many vessels target mixed species, which range in commercial value, and under current EU policy, it is mandatory to discard individuals that are not of minimum landing size (MLS) or an illegal species (Anon. 2003). These circumstances lead to prominent discarding in the Danish fisheries at an unknown level (Vestergaard and Jensen 2004). DTU Aqua began an on-board observer program in 1995 to understand the causes and effects of discarding (Anon. 2004, 2005, 2006, 2011; Feekings *et al.* 2012), however the results are not made publically available. In total, the observer program covers less than 1% of all trips made by Danish vessels within a year and does not include the pelagic or the industrial reduction fleet (Storr-Paulsen *et al.* 2010). This is due to the belief that there is little discarding in the pelagic fleet even though DTU has knowledge that high-grading occurs (Storr-Paulsen *et al.* 2010). Denmark began recording this information for national purposes, however in 2002, the European Data Directive (1639/2001) began requiring the collection of discard data (Madsen *et al.* 2012).

Within the last thirty years, the spawning stock biomasses (SSB) of many commercially important stocks have reached historical lows. This alarmed the EU and created a push for change in the CFP. In 2008, the CFP began to require recreational catch information in addition to discard data (Sparrevohn and Storr-Paulsen 2012b). It is only mandatory to collect Atlantic cod and European eel (*Anguilla anguilla*) catch data for this sector. In addition to this, Denmark began to collect data for sea trout (*Salmo trutta trutta*) l in 2010 (Sparrevohn and Storr-Paulsen 2010; Sparrevohn *et al.* 2011). In order to collect recreational catch information, Sparrevohn and Storr-Paulsen (2012b) created an interview-based survey for Danish residents. Nearly 17% of the Danish population identifies themselves as anglers (Sparrevohn and Storr-Paulsen 2012b). Anglers and passive gear fishers between 18 and 65 years old are required to purchase a license (Pawson *et al.* 2008; Sparrevohn and Storr-Paulsen 2012b).

Recreational fishing began in the 1950s with only few fishers targeting Atlantic cod and European eel from the shore (K. Manniche, pers. comm. Danmarks Sportsfiskerforbund). During this time, there was also a small subsistence fishery on the Wadden Sea coast of Jutland for European plaice (Holm 2005) and likely other flat fish species. With the invention of lighter fishing tackle, the popularity of recreational fishing grew (K. Manniche, pers. comm. Danmarks Sportsfiskerforbund). Recreational fishing peaked in the 1970s with larger catches of Atlantic cod and European eel correlated with higher SSB at the time (K. Manniche, pers. comm. Danmarks Sportfiskeforbund). In Denmark, there was another historical recreational fishery for Atlantic bluefin tuna (*Thunnus* thynnus),[2] which ended by 1964 due to the disappearance of stocks in the 1960s (MacKenzie and Ransom 2007). Sea trout fishing has only become more popular with a stock increase in the last 10 years resulting from a stocking initiative of smolts since 1991 (K. Manniche, pers. comm. Danmarks Sportsiskerforbund).

The purpose of the present report is to provide a preliminary, yet more inclusive estimate of total catch (i.e., including discarded catch) made by Danish commercial fishers within the Kattegat, Skagerrak and North Sea EEZ equivalent waters from 1950-2010. Denmark's total catch in the Baltic Sea has already been estimated separately in Bale *et al.* (2010) and Zeller *et al.* (2011). The reconstructed estimate includes both the reported landings and the so-called IUU, being Illegal, Unreported and Unregulated catch. Denmark's catch that is reported to the electronic catch database maintained by the International Council for the Exploration of the Sea (ICES) is used as the reported baseline catch over the time series being considered, since these are the data Europe reports to the global community via FAO. IUU catch is estimated here as unreported commercial catches, discarded, and recreational and subsistence catches. We make no distinction between legal or illegal catches, as our interest is in estimating total catches, not their legal status. The reconstructed catch estimates from 1950-2010 are estimated using ICES data, stock assessment reports, peer-reviewed literature, grey literature and expert opinions from local scientists and fishers.

Methods

ICES official reported landings data from the electronic database[3] are used as a reporting baseline for the reconstruction of Danish marine fisheries catches in the Skagerrak, the Kattegat and the North Sea. Estimates for IUU catches are made using qualitative and historical information, as well as expert opinion using a catch reconstruction approach as outlined by Zeller *et al.* (2007). These estimates are added to the reporting baseline to create the reconstructed total catch of Danish fisheries within their EEZ equivalent waters from 1950-2010.

[2] Tuna club http://www.tunaclub.dk/viewpage.php?page_id=1 (Accessed June 12, 2013)

[3] ICES http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx (Accessed June 2, 2012)

Landings data

Denmark's landing values provided publically by ICES are used as a baseline for the entire time series from 1950-2010. Denmark's EEZ is within ICES sub-area IIIa (Skagerrak and Kattegat) and division IVb (North Sea) (Figure 1). From 1950-1955, ICES reports catch in ICES division IVb. In 1956, catch values begin to be reported in ICES divisions IVa+b (unspecified) until 1973. From 1974-1977, the catches are separate among ICES divisions IVa, IVb and IVc for more commercially important taxa. Over the period 1978-1985, landings are reported in sub-area IV (unspecified). From 1986-1994, there are catches in sub-area IV and separately in divisions IVa, IVb, and IVc. Finally after 1995, all catches are separated specifically into the divisions of sub-area IV. In order to only include catches within the Danish EEZ (Division IV b), we calculate IV b's proportion of the total catch within area IV for years with division data, and those proportions are applied to years without more specific disaggregation of sub-area IV. The issues with spatial catch allocation to ICES areas may be the result of Denmark's national data having only been digitized since 1986 (B. Ueberschaer, pers. obs., GMA – Association for Marine Aquaculture Ltd.).

There are some discrepancies between national data and ICES data in regards to taxonomic categorization. For example, the national data reports shorthorn sculpin (*Myoxocephalus scorpius*) and sturgeon (*Acipenser sturio*), however these taxa are included in the general categories 'sculpins nei' and 'sturgeons nei' In the ICES database. Species such as John Dory (*Zeus faber*), ruffe (*Gymnocephalus cernua*) and poor cod (*Trisopterus minutes*) are included in the national data but have no category in the ICES database. Finally, some taxa such as cuttlefish in the national data are labeled *Octopus vulgaris*, however, this species' common name is common octopus, according to fishbase.[4] We choose to remain consistent and use the ICES database from 1986-2010 as opposed to the national data. It should however, be recognized that there are some small differences present between the two sources.

We split commercial landings into a large-scale industrial sector and a small-scale artisanal sector. We base our assumptions on Danish fleet statistics made publically available online,[5] qualitative information, and definitions from Martin (2012). Denmark has a long history and tradition of industrial fishing for reduction purposes, including for juvenile herring (*Clupea harengus*), European hake (*Merluccius merluccius*), whiting (*Merlangius merlangus*), Atlantic cod, Norway pout (*Trisopterus esmarkii*), European sprat (*Sprattus* sprattus) and sandeels (Byskov 2013). Pout, sprat and sandeels are exclusively fished for reduction purposes, and thus we tread their landings as 100% industrial. However, herring and cod are also caught for human consumption (more recently fishing for juvenile herring for reduction purposes was banned), and thus we split these as 50% artisanal and 50% large-scale in 1950, and 20% artisanal and 80% large-scale in 2010. The ratios for the rest of the time series are linearly interpolated and applied to each taxon for each year. As for invertebrate fisheries, deep water shrimps (*Pandalus* spp.), Norway lobster and brown shrimp (*Crangon* crangon) are considered 100% large-scale due to the mobile, bottom dragging gear used (Martin 2012). Finally, all other taxa are split 60% small-scale artisanal and 40% large-scale in 1950 and 20% small-scale artisanal and 80% large-scale in 2010. All values in between are interpolated linearly and industrial and artisanal ratios are applied to IUU catches for corresponding taxa. These sectoral designations are a highly simplifying assumption and local experts may have better knowledge of the division between large-scale commercial and small-scale commercial fisheries.

Illegal, Unreported and Unregulated catches

Unreported landings

ICES provides annual stock assessments (ICES 2002, 2003, 2012a, 2012b, 2012c, 2012e) in which they evaluate stocks of commercially important taxa in the northern Atlantic Ocean, the North Sea and the Baltic Sea. ICES stock assessments also report on estimates of so-called 'unallocated' catch (euphemism for 'unreported catches' and not assigned to a fishing country) provided as a total for all countries fishing a specific stock in a specific year. In order to estimate Denmark's portion of this unreported catch with

Table 1. Anchor points used to estimate the unreported landings of commercially important taxa in Denmark based on ICES stock assessment reports 1950-2010.

Taxon	ICES area	Assumed 1950 percentage of unreported landings	First year with available data	Anchor point from stock assessment (%)
European plaice	IIIa	1.1	1972	1.1
European plaice	IVb	5.0	1980	27.1
Common sole	IVb	0.5	1982	0.5
Saithe	IIIa	3.6	1990	3.5
Saithe	IVb	3.6	1990	3.6
Whiting	IVb	1.4	1993	1.4
Haddock	IVb	5.0	1992	27.6
Atlantic cod	IIIa	3.4	2002	3.4
Atlantic cod	IVb	5.0	1993	9.7
Atlantic mackerel	IIIa	5.0	1986	8.3
Atlantic mackerel	IVb	5.0	1986	8.3
Altantic horse mackerel	IIIa	5.0	1989	5.0
Atlantic horse mackerel	IVb	5.0	1989	5.0
Atlantic herring	IVb	5.0	2002	21.8

[4] Fishbase http://www.sealifebase.org/summary/Octopus-vulgaris.html (Accessed September 5, 2013)
[5] Ministry of Food, Agriculture and Fisheries of Denmark http://agrifish.dk/danish_vessels_by_type-_overall_length_and_tonnage.aspx?ID=24929 (Accessed September 18, 2013)

the data and information accessible to us, we assume proportionality between the reported landings by country and the 'unallocated' catches as presented in the stock assessment reports (see also Rossing *et al.* 2010; Zeller *et al.* 2011). Thus, we make the simplifying assumption that all fishing countries misreport in proportion to their reported landings, which clearly may not hold for all countries. Unfortunately, such simplifying assumptions of equal country treatment are necessary until ICES and its member countries comprehensively declare the origin of all catches. We treat positive 'unallocated' values as unreported catch.

The unreported catches vary substantially over time, and no data are available before the 1980s for most taxa for Denmark. In order to remain consistent with the methods used in Denmark's Baltic Sea report (Bale *et al.* 2010), and we calculate a rate of unreported catch as a percentage (unreported/landing+unreported) for the first year with available data for each taxon (Table 1). An assumed anchor point of 5% of unreported catch was assigned in 1950 for each taxon. The rate of unreported catch was interpolated between the first year of landed catch and the stock assessment anchor point. These rates were then applied to landings from corresponding years and taxa. If the anchor point rate from ICES stock assessments is less than 5%, that rate was carried back to 1950.

There are discrepancies between landing values in the ICES database and the ICES stock assessments for some taxa and years. The value ICES reports as landings in stock assessments can be significantly higher than the database catch for some taxa. As it has been repeatedly pointed out to us over the years that the assessment reports utilize better data, we accept the differences between ICES stock assessment values for landings and the electronic database values and add these as 'unreported' catches ('unreported' with respect to the electronic ICES database). We acknowledge that these values are not 'unreported' in the sense that ICES stock assessment personnel are aware of these values, however, these catches are not incorporated in the public database, which represents the public (and global) picture of fisheries catches for Europe.

Negative adjustments

Some 'unallocated' values in the ICES stock assessments are negative and represent over-reporting for the year. We assume the same proportionality as for unreported catches. For Denmark's proportion of over-reported values, we subtract these catches from the ICES baseline data. Just as for unreported catches, these adjustments are inconsistent and are not available before the 1980s, so we choose not to interpolate back to 1950 for any negative adjustments.

Discards

ICES provides some estimates of discards in their stock assessment reports, and presents these estimates similar to 'unallocated' catches. For example, discards are estimated as a tonnage of herring discards as a result of targeting herring for all European countries targeting the species in a specific area. We assume proportionality between Denmark's portion of the total European reported catch and Denmark's portion of European discards. For each taxon, an average discard rate is taken from the first three years of available data. We then apply the average discard rate to past catches with no available discard information. This creates discard tonnages for the entire time series 1950-2010. It is understood that changes in effort, quotas and gear restrictions over time may alter the rate of discarding. This may lead to a misreporting of Denmark's discards; however, provides the best possible estimation, since much of this information acquired by DTU is not publically available. This method of estimation is used for Atlantic herring, haddock, whiting, European plaice, Atlantic mackerel (*Scomber scombrus*) and Northern shrimp (*Pandalus borealis*). These taxa contribute approximately 22% to the total catch for Denmark. In order to estimate discards of other important taxa, we rely on data from Denmark's observer program.

DTU Aqua began an observer program in 1995 to collect discard data for most gear types (Storr-Paulsen *et al.* 2010; Feekings *et al.* 2012; Madsen *et al.* 2012), unfortunately we are not privy to DTU Aqua's discard data in detail.[6] In the DTU Aqua report for sampling of commercial fisheries in 2010 (Storr-Paulsen *et al.* 2010), there are discard estimates for most gear types and areas in the Danish fleet. Data are provided as a total catch observed, total discards observed, and discard rate by species, gear type and ICES areas (Storr-Paulsen *et al.* 2010). For taxa that are not assessed by ICES or do not include discard estimates in ICES stock assessments, we use the discard rates provided by Storr-Paulsen *et al.* (2010). We apply the discard rate to our estimated total commercial catches (i.e., after accounting for unreported and over reported catches) back to 1950 to complete the time series. However, we excluded taxa with a gear-type- or fishery-specific discard rate of 100% as reported in Storr-Paulsen *et al.* (2010) in order for our estimate to remain conservative.

We believe that discard rates of some taxa presented in the DTU observer program report (Storr-Paulsen *et al.* 2010) may be higher than actual overall rates. We believe that this discrepancy is a result of the lack of observer coverage on pelagic and industrial fishmeal vessels. In order to deal with this issue, we have decided to use discard rates from the German North Sea fisheries as a proxy for Atlantic cod and American plaice (*Hippoglossoides platessoides*) (Gibson *et al. in press*). We recognize that this may add uncertainty; however the two countries both operate under the European Commission's Common Fisheries Policy (CFP), and both fish within ICES division IVb. Therefore, each country operates under the same quota regulations with similar species distributions in their waters, and similar types of vessels.

[6] We would like to point out that marine resources are owned by the public, and as such the public should benefit from full disclosure of all information pertaining to the use of their resources, including all data on discarded catches. Obviously, any fishing vessel identifiers can be removed for such data releases.

Recreational catch

The European Commission's CFP requested member states to begin monitoring and estimating the catches of recreational fisheries in 2008 (Sparrevohn and Storr-Paulsen 2012a, 2012b). As a result, Denmark began to estimate catches of Atlantic cod and European eel using a recall survey in 2009 (Sparrevohn and Storr-Paulsen 2010; Sparrevohn *et al.* 2011; Sparrevohn and Storr-Paulsen 2012a). Sea trout was added to the survey in 2010 (Sparrevohn *et al.* 2011; Sparrevohn and Storr-Paulsen 2012a). DTU Aqua reports (Sparrevohn and Storr-Paulsen 2010; Storr-Paulsen *et al.* 2010; Sparrevohn *et al.* 2011; Sparrevohn and Storr-Paulsen 2012a) provide catch values as well as catch and release numbers for these species since 2009 for various bodies of water surrounding Denmark. Our recreational catch anchor points estimated from these reports include both passive gear and angling catches, as well as DTUs estimate of illegal catches from Kattegat, Skagerrak, the North Sea and Limfjorden (Table 2). Data for cod in 2009 and 2010 (Sparrevohn and Storr-Paulsen 2010; Sparrevohn *et al.* 2011) are averaged to avoid an unrealistic spike in 2010 recreational catches. The average is used as anchor points for both 2009 and 2010. An ICES report on recreational fishing surveys is used as confirmation for cod and eel catches (ICES 2012d).

Prior to the European Commission requesting that its member states begin to monitor recreational fisheries, there is little information on Danish recreational catches. Recreational information is often presented qualitatively. Therefore, the anchor point estimates we present are based on DTU Aqua reports and personal communication with fellow researchers and recreational fishers (Table 2). Flatfish species such as European plaice, European flounder (*Platichtys flesus*) and common dab (*Limanda limanda*) as well as garfish (*Belone belone*) are caught in relatively large numbers for sport purposes, but are not included in DTU Aqua surveys (K. Manniche, pers. comm. Danmarks Sportfiskeforbund). For garfish, we use the same anchor points that are used for sea trout (Table 2). For flatfishes, we use half the anchor points for cod and then divide that value equally among the three commonly caught species of flatfish (Table 2).

Table 2. Anchor points to estimate recreational catches (in tonnes) from 1950-2010. Dashed line (-) indicates years in which linear interpolations were used.

Year	Atlantic cod	Sea trout	European eel	Garfish	European plaice	European flounder	Common dab	Atlantic bluefin tuna
1950	463	0	195	0	77	77	77	-
1959	-	-	-	-	-	-	-	0.3
1964	-	-	-	-	-	-	-	0.0
1970	926	-	-	-	154	154	154	-
1992	-	167	-	167	-	-	-	-
2009	545	-	39	-	91	91	91	-
2010	545	167	43	167	91	91	91	-

Subsistence catch

Recreational fishing occurs with the intention of pleasure regardless of whether the catch is consumed or not (Pawson *et al.* 2008). Subsistence fishing, however, is primarily driven by fishing for consumption by fishers and their families (Sowman 2006; Schumann and Macinko 2007). Clearly, over time, these two components have overlapped and replaced each other in Europe. Fishing for flatfish on the western coast of Jutland occurred after World War II in small amounts (Holm 2005). From this, we assume that there was a small amount of subsistence fishing in the rural regions of Jutland during the early time period, and we assume that 'subsistence' *per se* ended by the 1970s. Therefore, we arbitrarily select an anchor point of 500 t for subsistence catch in 1950, and linearly interpolate to 0 t of true subsistence catch by 1970. We then apply the same proportions of taxa present in the estimated recreational catches to the subsistence catch for each year.

Results

Landings

The reported landings within Denmark's Kattegat, Skagerrak and North Sea EEZ from 1950-2010 are just over 52 million t (Figure 2a). Landings from the Kattegat and Skagerrak (ICES sub-area IIIa) represent approximately 26% of the total reported landings

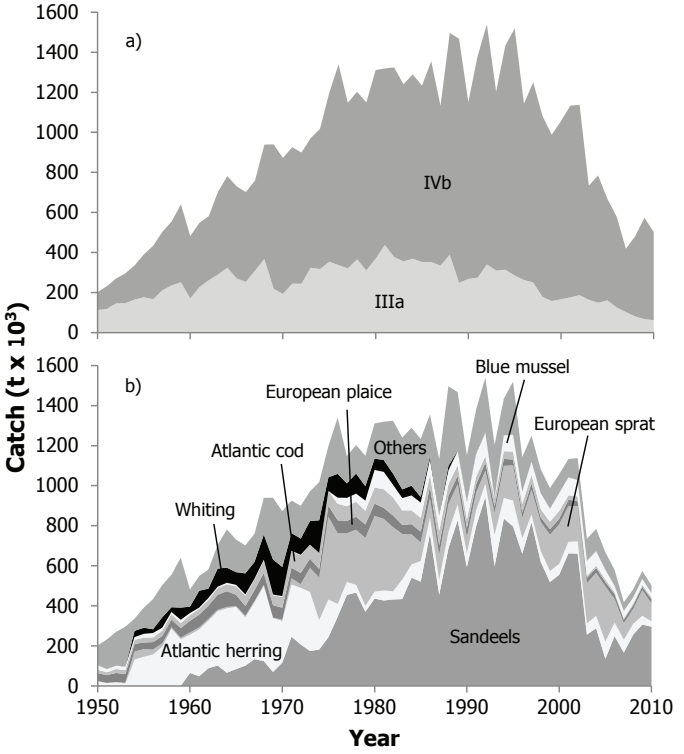

Figure 2. Reported landings by Denmark's fisheries from the Kattegat, Skagerrak and North Sea EEZ equivalent waters for 1950-2010, by a) ICES area; and b) major taxa.

from 1950-2010 (Figure 2a). Danish reported landings steadily increased from around 178,000 t in 1950 to their peak in 1992 with a landed catch of 1.5 million t (Figure 2a). Annual landed catch then decreases steadily to reach 499,000 t by 2010. Taxa fished for reduction purposes such as Sandeel, European sprat and Atlantic herring dominate the reported landings data, comprising 40%, 14% and 13% of reported landings from 1950-2010, respectively (Figure 2b).

Illegal, Unreported and Unregulated (IUU) catches

Unreported catch

The estimated unreported commercial catch totals just under 753,000 t over the time series for the taxa available. Atlantic herring comprises 62% of this value. Other taxa included European plaice, Atlantic cod, haddock, Atlantic mackerel, Saithe (*Pollachius virens*), whiting, Atlantic horse mackerel (*Trachurus trachurus*), and Common sole (*Solea solea*) (Figure 3).

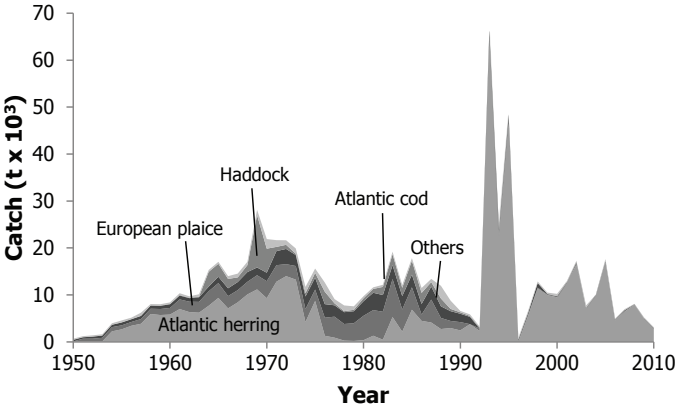

Figure 3. Denmark's unreported catches associated with commercial fisheries, as unreported commercial landings.

Discards

Danish discards in the Skagerrak, Kattegat and North Sea are estimated at 3.3 million t from 1950-2010 (Figure 4). Discards seem to be at their highest in the 1970s (on average 83,000 t·year^{-1}), but remain at fairly high levels (1995-2005 average: 49,000 t·year^{-1}). By 2010, discards had decreased to around 15,000 t. Whiting contribute approximately 31% to the total; however, they are only high in the early period of the time series. European plaice represents 16% of the total discards and average 9,000 t·year^{-1} (Figure 4). Haddock, roundnose grenadier (*Coryphaenoides rupestris*), Atlantic cod, and common dab comprise 12%, 11%, 7% and 6% of total discards, respectively. All of the top discarded groups are common by-catch in mixed demersal trawls in all waters of Denmark's EEZ.

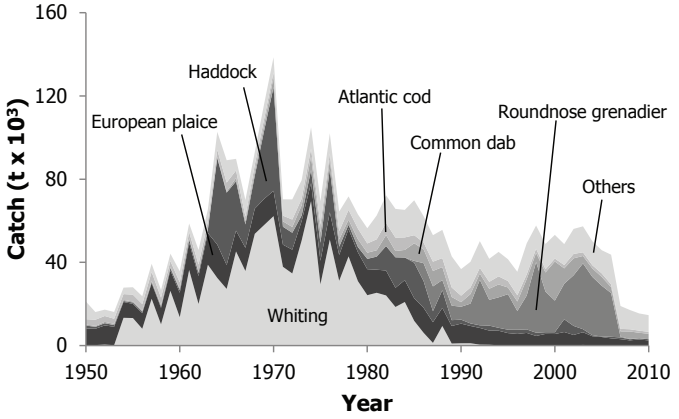

Figure 4. Denmark's unreported catches associated with commercial fisheries, as discards in its Kattegat, Skagerrak and North Sea EEZ from 1950-2010.

Recreational catches

Denmark's total recreational catch over the time series is estimated at around 86,000 t (Figure 5). Atlantic cod is the most important recreational species, comprising 51% of the total catch. Recreational catches as estimated here remain relatively consistent over the time series; however, they seem to have been declining since the 1970s. However, while the overall trend represented by our data seems appropriate, detailed variation is not well reflected in our data, given the limited data available on this sector, and the assumptions we consequently had to employ. European plaice, European flounder and common dab represent 8% each of the recreational total catch. All flatfishes follow a similar trend to cod; there is an initial increase however, catches have been declining since the 1970s. European eel represents 8% of the total catch, but demonstrates a gradually declining trend over time. Sea trout has only recently become a more popular species to target since restocking programs beginning in the early 2000s seem to have been successful (K. Manniche, pers. comm. Danmarks Sportsfiskerforbund). They each represent approximately 8% of the total catch and show an increasing trend over the time series (Figure 5).

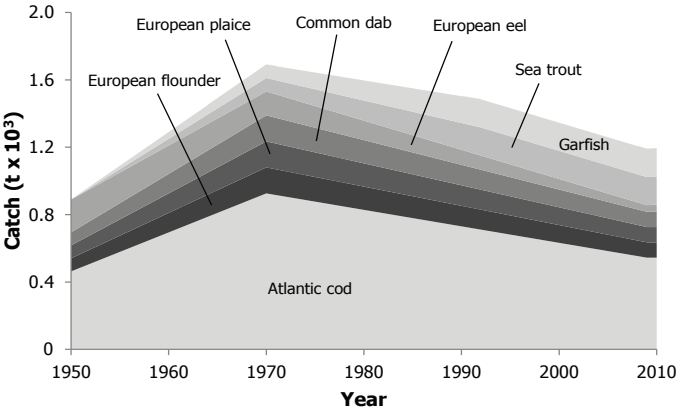

Figure 5. Denmark's reconstructed recreational catch, 1950-2010.

Subsistence catch

The total estimated subsistence catch for Denmark from 1950-1970 is just over 5,250 t. Atlantic cod represents the largest portion of this catch (53%). Subsistence catches were highest in 1950 (500 t) but were deemed to have ended by 1970.

Total catches

The reconstructed total Danish catch within their Kattegat, Skagerrak and North Sea EEZ equivalent waters from 1950-2010 is 56.9 million t, which is 1.13 times higher than the reported catch of 50 million t within the same spatial and temporal parameters (Figure 6a). Discards of approximately 3.3 million t comprise the largest component of unreported catches, accounting for 6% of the reconstructed total catch. Sandeel are by far the largest taxonomic contributor to the reconstructed catch, comprising 36% of the total catch (Figure 6b). Atlantic herring, European sprat, European plaice, Atlantic cod, blue mussel and whiting contribute 14%, 13%, 5%, 5%, 5% and 4% respectively (Figure 6b).

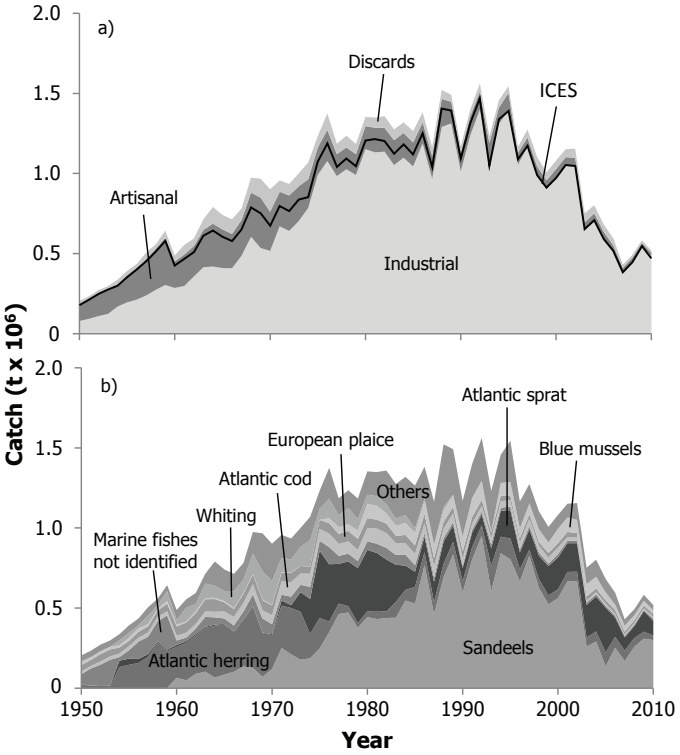

Figure 6. Reconstructed total catch for Danish fisheries within their Kattegat, Skagerrak and North Sea EEZ equivalent waters from 1950-2010, by a) fishing sector, plus discards. Note the overlaid black dotted line represents the official ICES reported landings baseline; and b) major taxa with 'Others' containing - additional taxonomic categories.

Discussion

The present, preliminary reconstruction of Danish total catches in their Kattegat, Skagerrak and North Sea EEZ equivalent waters from 1950-2010 is 54 million t, which is 1.09 times greater than the reported catch of 50 million t. Discards are the largest contributor to the reconstructed catch over the whole time series. However, unreported catch and the ICES stock assessment adjustments do make a notable contribution. As estimated here, recreational and subsistence catches have a very small contribution to the overall reconstruction. The relatively low discrepancy (9%) between reported and reconstructed total catches, compared to other countries in the region (Rossing *et al.* 2010) could be driven by the predominance of the reduction fisheries in Denmark, which likely has low discarding.

In the mid 1980s, Denmark switched from recording fisheries data on paper, to digitizing data (B. Ueberschaer, pers. obs., GMA – Association for Marine Aquaculture Ltd.). Catch data from the earlier decades has not yet been digitized, which results in some uncertainty in ICES landings data for these decades. There are few discrepancies in regards to catch values and taxa between the national data and ICES reported landings. ICES reports higher landings in miscellaneous categories in the earlier decades but in the 1960s and 1970s, taxa begin to have more specific taxonomic designations.

Discarding is a practice that is a cause for concern in all fisheries on a global scale. Denmark initiated an observer program in 1995 in order to investigate these concerns (Anon. 2004, 2005, 2006, 2011; Feekings *et al.* 2012). Much of these data are not available to the public; however there are a few reports that use these data. In 2010, the observer program recorded approximately 21,500 t, which is 26% of the total catch from all fleets excluding pelagic and industrial reduction catches (Storr-Paulsen *et al.* 2010). While discard rates may in fact be low in these fisheries, their total landed catch represent a large proportion of the total Danish catch on an annual basis. Therefore, the discards likely add up to reach a more substantial value. In order to have a reliable and transparent handle on actual catches and discards, 100% observer coverage is required in all fisheries and all gears (Zeller *et al.* 2011), which has been shown to be effective in creating stakeholder buy-in and increased accountability and transparency in fisheries (Branch 2006). It has also been shown to be achievable and successul in moving fisheries to sustainability.

Our reconstructed estimate of discards for 2010 is approximately 14,600 t. The difference between our reconstructed discards and DTU's observed discarded catch is likely due to a combination of factors. We made a large effort to remain conservative with our estimate by excluding all taxa with a gear-specific discard rate of 100% from Storr-Paulsen *et al.* (2010). There are many species such as thorny skate (*Amblyraja radiata*), dragonet (*Callionymus lyra*), hooknose (*Agonus cataphractus*) etc. that are likely discarded in significant amounts, but are excluded from our estimates. Also, our estimate of the Danish discard tonnage does not include the discards that would be a result of catches made in the Baltic Sea (see Rossing *et al.* 2010; Zeller *et al.* 2011). Thus, our estimates are likely underestimates of the total level of discarding in all of Denmark's current fisheries.

Juvenile Atlantic herring was targeted for reduction purposes in the earlier decades, while mature individuals were being taken for human consumption (Byskov 2013). The combined fishing pressure contributed to a stock crash and the herring fishery was closed in the 1970s for approximately 10 years (Nielsen 1989; Byskov 2013). The spawning stock biomass (SSB) of Atlantic cod reached an all time low in 2006 (ICES 2013) and sandeel SSB was at a three year historical low in the mid 2000s (Nielsen and Mathiesen 2006; Byskov 2013). The critical state of these stocks is reflected in the reported landings (Figure 2b). However, excessive fishing effort and inconsistent recording, reporting and monitoring of landed catch are not the only factors contributing to these substantial declines.

Atlantic cod was the most commercially important species in Europe and specifically in the Kattegat in the early portion of our time series, but stocks have been decreasing for 30 years (Madsen and Valentinsson 2010). The low numbers of Atlantic cod have caused ICES to advise zero catch of cod within the Kattegat (Madsen and Valentinsson 2010). This is difficult to execute because Norway lobster is now the most valuable commercial species in the Kattegat (Frandsen *et al.* 2009) and Atlantic cod is common as by-catch of this trawl fishery (Catchpole and Revill 2008). Much of the discarded by-catch from the Norway lobster trawl are juvenile fish, and are dead or dying when discarded (Catchpole and Revill 2008). These discards likely add substantial mortality to cod stocks that are already at dangerously low levels (Froese and Quaas 2012).

Juvenile European plaice is also commonly discarded in Norway lobster and sole fisheries, as well as in shrimp fisheries (Dickey-Collas *et al.* 2007; Feekings *et al.* 2012). A combination of small mesh size, poor escapement and stress cause plaice, especially juveniles to be common in discarded by-catch (van Beek *et al.* 1989; Feekings *et al.* 2012). European plaice is the most important flatfish species in commercial fisheries (Madsen *et al.* 2012); however, discarding of juveniles in particular has always been a problem in Danish North Sea fisheries (Daan 1997). A 'plaice box' was established in 1989 as a protective management measure (Daan 1997; Pastoors *et al.* 2000; ICES 2002, 2012b). The plaice box covers the North Sea coast of Denmark, Germany and the Netherlands (Pastoors *et al.* 2000). It also overlaps with the Danish portion of the Wadden Sea, which is completely closed for fishing except the outermost 1 nm can be trawled for shrimp (Holm 2005; Lotze 2007). It is likely that juvenile plaice are still discarded in this fishery, however within the last 10 years, the European plaice stock in the North Sea has been increasing (ICES 2013).

The Danish fisheries allocate substantial effort to trawling the North Sea targeting sandeel for reduction purposes. Reduction fisheries are believed to have very low discarding rates (Kelleher 2005; Storr-Paulsen *et al.* 2010). However, sandeel spend most of their time partly burrowed in sand (Pedersen *et al.* 1999). It is likely that many invertebrates may also be caught as by-catch, due to the nature of this gear type, and may not be retained for reduction. These discards are not included in our estimate of discards or in DTU's observer estimate of discards. Therefore, DTU's own estimate may also be an underestimate.

Considering the popularity of recreational fishing within Denmark, it does not comprise a large portion of the total reconstruction. Our estimate of the Danish recreational catch is based on expert opinion and data for only two years (2009 and 2010). The EU and Denmark are taking steps to survey recreational fishers on an annual basis, however there is still some illegal recreational fishing that does occur (Sparrevohn and Storr-Paulsen 2010; Sparrevohn *et al.* 2011; Sparrevohn and Storr-Paulsen 2012a, 2012b).

The European Union is taking steps to more accurately monitor fisheries and their catches to avoid stock crashes. In 2013, the CFP is being reformed and has initiated plans for an eventual EU wide discard ban or discard reductions (Feekings *et al.* 2012). Still, government organizations like DTU and ICES need be more transparent to the public with the information that they collect. The public should be allowed access to this information in order to understand management decisions instead of having to accept them blindly. If the past is any indication, changes to both management and collection as well as sharing of data are necessary within the EU's CFP.

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

Year	ICES	Reconstructed total catch	Industrial	Artisanal	Subsistence	Recreational	Discards
1950	177,563	204,000	79,000	103,000	500	890	21,100
1951	212,489	234,000	92,500	124,000	475	930	16,100
1952	248,936	271,000	109,800	143,000	450	970	17,300
1953	275,584	297,000	123,400	156,000	425	1,010	16,200
1954	299,617	337,000	169,200	139,000	400	1,050	27,800
1955	353,388	392,000	195,300	167,000	375	1,090	28,000
1956	399,211	435,000	211,800	198,000	350	1,130	23,700
1957	451,687	506,000	238,200	227,000	325	1,170	39,300
1958	512,458	558,000	273,300	256,000	300	1,210	26,700
1959	580,121	643,000	303,400	294,000	275	1,250	44,200
1960	425,182	488,000	285,300	166,000	250	1,290	35,700
1961	466,520	555,000	297,900	197,000	225	1,330	58,700
1962	508,508	594,000	356,800	189,000	200	1,370	45,900
1963	610,144	714,000	414,500	233,000	175	1,410	65,500
1964	644,052	791,000	419,200	267,000	150	1,450	102,700
1965	604,331	741,000	409,500	241,000	125	1,490	89,100
1966	577,797	714,000	408,000	214,000	100	1,530	89,800
1967	649,206	781,000	486,100	223,000	75	1,570	69,900
1968	788,291	975,000	604,800	275,000	50	1,610	93,000
1969	751,582	967,000	534,800	314,000	25	1,650	116,200
1970	673,400	901,000	516,100	245,000	-	1,690	138,600
1971	797,023	957,000	669,800	215,000	-	1,681	70,300
1972	765,520	935,000	641,500	221,000	-	1,671	70,300
1973	836,700	1,001,000	702,400	217,000	-	1,662	79,500
1974	852,742	1,070,000	785,500	178,000	-	1,653	104,900
1975	1,073,311	1,233,000	991,500	170,000	-	1,643	69,400
1976	1,187,980	1,375,000	1,077,300	194,000	-	1,634	102,000
1977	1,040,914	1,186,000	983,900	136,000	-	1,625	64,400
1978	1,093,218	1,236,000	1,026,300	136,000	-	1,615	71,700
1979	1,045,441	1,184,000	990,400	129,000	-	1,606	63,000
1980	1,206,411	1,353,000	1,151,800	143,000	-	1,597	56,400
1981	1,214,983	1,349,000	1,132,100	153,000	-	1,587	62,500
1982	1,203,490	1,358,000	1,136,300	148,000	-	1,578	72,200
1983	1,123,274	1,275,000	1,052,200	155,000	-	1,568	65,700
1984	1,182,467	1,319,000	1,098,700	154,000	-	1,559	65,200
1985	1,118,406	1,265,000	1,043,700	149,000	-	1,550	69,800
1986	1,250,076	1,382,000	1,187,700	131,000	-	1,540	62,200
1987	1,039,324	1,164,000	967,200	142,000	-	1,531	53,100
1988	1,405,625	1,522,000	1,290,300	175,000	-	1,522	55,600
1989	1,392,711	1,492,000	1,312,500	135,000	-	1,512	42,900
1990	1,093,620	1,169,000	1,012,500	119,000	-	1,503	36,800
1991	1,316,391	1,401,000	1,238,700	121,000	-	1,494	40,200
1992	1,468,065	1,562,000	1,398,600	112,000	-	1,484	50,200
1993	1,047,836	1,232,000	1,073,600	115,000	-	1,467	41,700
1994	1,339,438	1,457,000	1,311,000	100,000	-	1,450	45,000
1995	1,390,696	1,545,000	1,389,600	112,000	-	1,432	41,500
1996	1,089,595	1,165,000	1,053,900	75,000	-	1,415	35,500
1997	1,172,285	1,275,000	1,168,400	56,000	-	1,398	49,200
1998	990,158	1,104,000	983,700	61,000	-	1,380	57,700
1999	911,388	1,007,000	900,600	56,000	-	1,363	48,900
2000	971,899	1,082,000	970,700	56,000	-	1,346	53,200
2001	1,053,536	1,151,000	1,046,500	55,000	-	1,328	48,800
2002	1,046,255	1,155,000	1,042,300	55,000	-	1,311	56,100
2003	653,059	752,000	645,700	48,000	-	1,294	57,300
2004	708,947	802,000	700,300	50,000	-	1,276	50,100
2005	589,251	682,000	590,200	44,000	-	1,259	45,800
2006	517,524	595,000	517,000	34,000	-	1,242	43,700
2007	382,631	430,000	380,200	30,000	-	1,224	19,000
2008	446,344	492,000	447,900	26,000	-	1,207	17,100
2009	545,924	583,000	543,300	23,000	-	1,190	15,400
2010	470,499	519,000	485,900	17,000	-	1,194	14,600

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

Year	Ammodytidae	*Clupea harengus*	*Sprattus sprattus*	Marine fishes not identified	*Gadus morhua*	*Pleuronectes platessa*	*Mytilus edulis*	*Merlangius merlangus*	Others
1950	-	22,300	2,810	62,000	17,400	39,300	22,700	543	37,100
1951	-	13,700	1,270	107,900	15,300	38,600	16,400	557	40,000
1952	-	17,500	2,150	126,500	20,400	45,200	17,300	1,073	41,300
1953	-	11,600	3,830	161,300	21,300	43,400	16,800	452	38,500
1954	-	131,600	40,040	22,500	22,000	37,400	13,900	30,928	38,700
1955	-	145,600	38,220	53,300	25,100	33,400	18,600	30,675	47,200
1956	-	157,100	24,870	108,600	24,100	36,800	22,400	18,728	42,600
1957	-	195,800	16,810	108,600	27,100	36,700	15,300	52,138	53,100
1958	-	286,200	7,060	124,200	27,500	38,800	10,800	23,695	39,300
1959	-	233,400	7,210	213,000	26,200	48,300	16,200	60,969	37,700
1960	64,800	192,800	11,260	28,400	29,800	58,000	10,000	31,770	61,400
1961	48,700	234,800	9,890	22,300	29,800	64,200	6,200	84,578	54,200
1962	89,200	240,000	9,150	34,200	29,100	66,700	10,400	46,888	68,000
1963	102,500	273,300	6,990	62,100	34,900	75,500	6,700	90,691	61,500
1964	66,100	323,500	6,980	45,100	35,100	79,200	7,900	75,771	151,200
1965	84,700	312,800	3,500	33,900	44,100	56,800	7,200	63,608	134,600
1966	102,200	244,300	6,400	38,100	53,200	49,700	5,900	105,798	108,200
1967	135,400	288,500	5,480	48,200	54,800	55,700	4,200	84,271	104,100
1968	126,700	383,200	5,250	69,900	63,700	61,000	3,800	127,150	133,900
1969	70,600	273,000	3,030	88,900	50,800	62,800	4,000	177,037	236,900
1970	118,900	211,700	6,120	62,700	56,300	61,200	3,700	147,091	233,800
1971	250,300	264,900	31,680	36,200	83,300	53,500	3,900	89,380	144,000
1972	211,300	288,700	18,480	52,800	89,800	57,600	3,000	82,090	130,900
1973	177,100	299,800	121,960	46,700	70,200	46,800	1,300	119,072	117,900
1974	186,700	151,300	218,780	74,800	82,700	44,200	-	165,722	145,600
1975	247,300	190,600	419,850	61,800	74,500	56,500	-	69,289	113,000
1976	349,600	66,100	357,710	107,100	84,400	65,300	31,000	119,786	194,400
1977	462,600	65,100	248,310	49,200	75,100	62,200	42,500	73,433	107,400
1978	472,500	39,600	279,040	48,700	76,500	65,500	41,500	100,763	111,800
1979	376,300	29,700	343,810	43,200	69,900	69,200	51,600	72,878	127,700
1980	443,300	35,300	384,220	53,800	82,200	62,400	89,400	57,075	145,400
1981	431,300	50,900	361,660	57,600	95,000	55,100	87,800	59,497	150,300
1982	437,600	41,000	324,510	73,000	92,000	59,500	63,300	56,600	210,600
1983	439,900	98,700	231,130	61,300	74,100	45,900	62,700	43,659	217,500
1984	547,000	66,500	151,670	68,600	70,500	52,200	75,200	49,139	238,400
1985	527,400	104,700	93,830	41,700	70,600	54,300	77,200	27,908	266,900
1986	767,400	81,500	96,300	23,600	60,000	59,700	79,600	14,430	199,700
1987	461,900	73,900	127,240	27,000	72,000	49,700	81,000	3,026	267,900
1988	692,600	84,000	138,440	21,700	58,600	43,200	69,700	22,035	392,100
1989	834,100	79,700	102,320	20,800	53,400	41,800	72,300	2,303	284,800
1990	598,100	68,700	81,740	15,500	44,000	46,800	88,800	2,600	223,100
1991	803,200	78,900	90,520	17,000	38,700	41,200	116,200	2,617	212,700
1992	950,100	67,300	65,250	19,500	33,800	39,700	118,400	1,191	267,100
1993	605,000	159,300	107,990	24,600	40,600	34,000	4,900	866	254,500
1994	842,300	103,300	161,960	19,100	39,400	34,600	80,400	396	175,800
1995	803,800	129,800	177,360	22,200	40,500	29,400	84,500	194	257,100
1996	666,500	76,300	103,870	19,000	43,900	27,500	60,700	132	167,500
1997	825,900	38,800	125,950	21,500	44,300	30,200	66,000	77	121,800
1998	625,500	55,100	146,710	18,900	42,500	23,000	79,600	62	112,700
1999	523,400	55,700	182,880	15,400	38,600	27,700	65,500	84	97,400
2000	562,100	54,300	200,070	21,000	40,700	27,400	89,800	135	86,200
2001	667,300	58,100	179,560	15,300	22,800	31,900	90,800	185	85,600
2002	665,900	61,100	177,810	14,600	23,400	25,800	82,500	291	103,600
2003	259,700	56,200	203,440	15,100	11,600	26,700	75,700	446	103,000
2004	291,000	63,000	217,260	14,500	13,100	23,700	72,900	288	106,300
2005	136,400	86,900	279,160	11,300	13,700	21,100	48,900	127	84,000
2006	252,400	68,200	120,130	13,200	10,300	23,500	33,000	422	74,400
2007	168,600	65,400	82,890	9,300	8,100	18,000	37,000	123	40,600
2008	258,000	54,300	74,550	8,400	9,800	18,800	30,300	94	37,600
2009	308,500	44,100	128,830	7,000	9,500	17,200	30,700	113	36,900
2010	300,400	28,000	91,210	14,200	10,600	19,600	21,900	79	33,000