Review of red-throated diver prey species in the Thames Estuary

CORK ♦ ECOLOGY

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1. Summary

- A review of the potential prey species of red-throated diver in the Thames Estuary over the winter period was conducted by Cork Ecology.

- Previous studies elsewhere found cod, herring, sprat and whiting to be the most important prey species by weight.

- Fish species known to be red-throated diver prey items that occur or are likely to occur in the Thames Estuary were reviewed (Table 1).

- Species accounts outline the life history, habitat, behaviour, distribution and abundance within the Thames Estuary.

- From the available information, it is likely that the chief prey items of red-throated divers in the Thames Estuary during winter are herring and sprat. In addition, sand gobies, whiting and flatfish such as flounder and dab may also be important.

- In order to determine more precisely what fish species are present in areas where higher numbers of red-throated divers were recorded on aerial surveys (Appendix A), winter fishing surveys should be carried out.

2. Introduction

A review of the prey species of red-throated diver (*Gavia stellata)* in the Thames Estuary was conducted by Cork Ecology at the request of CORE Ltd, as part of a series of background studies for the proposed London Array Wind Farm in the Thames Estuary.

Aerial and boat-based baseline bird surveys in the vicinity of the proposed London Array offshore wind farm have highlighted the presence of large numbers of red-throated divers primarily between November and March (Appendix A). In order to further identify and characterise the parts of the study area of particular importance for the divers, Cork Ecology were commissioned to conduct a desk study review of the ecology of the prey species of the divers.

Red-throated divers are almost exclusively piscivorous, selecting small teleost fish up to 25 cm in length (Cramp and Simmons 1977). A Danish study found that fish between 4 and 15 cm were taken during the winter (Durinck *et al* 1994). As prey is located visually, clear waters are favoured for foraging and they do not fish at night (Ivory 1999). Prey are caught in dives which average 1 minute and depths of 2-9 m have been recorded (Cramp & Simmons 1977). When a suitable prey species is found in abundance, red-throated divers will fully exploit it. (Ivory 1999).

Occasionally invertebrates may be taken, sometimes to feed young although traces found in diver stomachs may have already been present in fish that were eaten. Plant material has been recorded in birds in the high arctic on iced over waters with no other food available (Cramp & Simmons 1977).

A wide variety of fish species are taken and the species relevant in the context of the Thames Estuary are considered here.

3. Methods

Study Area

The whole of the Thames Estuary was considered for this desk study, which includes the aerial survey study area for the London Array wind farm, and also includes two other proposed wind farm sites at Greater Gabbard and Thanet (Appendix A).

Species reviewed

Twenty-three species of fish were considered in this review, based on information concerning the diet of red-throated divers, and the known distribution of these species (Table 1). Most of the fish species reviewed here are listed in Cramp & Simmons (1977) as prey items for red-throated divers. In addition whiting, dab and long-rough dab were found in red-throated diver stomachs in a Danish study (Durinck *et al* 1994). Not all the goby and sandeel species were specifically named in the above references, and so species were included based on their likely distribution in the Thames estuary.

Table 1. Species included in Thames diver prey review

Order	Family	Common name	Latin Name
Clupeiformes	Clupeidae	Herring	*Clupea clupea*
		Sprat	*Sprattus sprattus*
Gadiiformes	Gadidae	Cod	*Gadus morhua*
		Whiting	*Merlangius merlangus*
Gasterosteiformes	Gasterosteidae	Three-spined stickleback	*Gasteroseus aculeatus*
		Fifteen-spined stickleback	*Spinachia spinachia*
		Nine-spined stickleback	*Pungitius pungitius*
Perciformes	Ammodytidae	Common sandeel	*Ammodytes tobianus*
		Raitt's sandeel	*A. marinus*
		Greater sandeel	*Hyperoplus lanceolatus*
	Pholidae	Butterfish	*Pholis gunnellus*
	Gobiidae	Rock goby	*Gobius paganellus*
		Black goby	*G. niger*
		Giant goby	*G. cobitis*
		Sand goby	*Pomatoschistus minutus*
		Common goby	*P. microps*
		Painted goby	*P. Pictus*
		Two-spotted goby	*Gobiusculus flavescens*
		Crystal goby	*Crystallogobius linearis*
		Transparent goby	*Aphia minuta*
Pleuronectiformes	Pleuronectidae	Flounder	*Platichthys flesus*
		Dab	*Limanda limanda*
		Long-rough dab	*Hippoglossoides platessoides*

Data Sources

Relevant information was taken from three specific studies on fish in and around the Thames Estuary:

CEFAS conducted a series of surveys sampling the distribution and abundance of young fish on the east and south coast of England (1981 to 1997) (Rogers *et al* 1998).

A long-term study sampling fish in the middle Thames estuary at West Thurrock Power station between 1977-1992 provided information for several species (Power & Attrill 2000 a & b; Power *et al* 2002 a & b).

The Thames Estuary herring stock (Wood 1981).

In addition, reference was also made to Dipper (2001), Miller & Loates (1997), Lythgoe & Lythgoe (1971), Lee & Ramster (1981), Wheeler (1969), Muus (1974), Knijn *et al* (1993) and various websites for information on species ecology.

A review of available relevant literature was also carried out.

Limitations of the species accounts

Most published information on inshore fish species is concerned with species of commercial value (Ducrotoy *et al* 2000, in Power & Attrill 2002a). Because of the costs associated with data collection and analysis, little systematic effort has been invested into researching the status and biology of non-commercial species (Swaby & Potts, 1990 in Power & Attrill 2002a). As a consequence few data are available for some of the fish species in this review.

Note spawning areas are not fixed and may vary from year to year. Times of spawning may also vary. Where possible spawning times are given for the Thames Estuary or for the south of England or southern North Sea. Similarly water temperature and food availability can affect nursery areas so the exact locations can vary between years.

Note the study in the middle Thames Estuary was carried out to the west of the main area of interest for this review and may not be entirely representative of fish distribution further east.

4. Accounts of Prey Species

The following species accounts give a brief outline of the life history, habitat and behaviour for the 23 species considered in this report, along with a description of their distribution and abundance within the Thames Estuary.

Herring

Life history

Herring is a pelagic schooling species that grows up to 40 cm in length. There are many races of herring, each with their own preferred areas, spawning habits and migrations (Lythgoe & Lythgoe 1971).

In the Thames Estuary there is a stock of the coastal race of herring known as the Thames Estuary or Blackwater herring. The stock is self-contained and does not intermix with other similar stocks in nearby areas (Wood 1981).

Herring are demersal spawners, depositing their sticky eggs on coarse sand, gravel, small stones and rock. Shoals of herring gather on the spawning grounds and spawn more or less simultaneously (FRS 2004). First spawning is between 2-4 years but is mostly at the age of 3 in the Thames Estuary, between early February to early May (Wood 1981). The eggs hatch after about three weeks and the larval herring remain close to the coast for a few months. Metamorphosis occurs in July-August when 3-3.5 cm.

The Thames estuary herring are generally smaller in size to the Atlantic herring found in the North Sea. After 1 year, the herring measure 5-12 cm long. Two year old herring are 15-22 cm in length. By the age of 3 when most fish are mature, they will be c. 23 cm, increasing to c.25 cm by the following year. Few fish live longer than 11-12 years (Wood 1981).

Prey species include crustaceans and juvenile sandeels but herring can also filter-feed for zooplankton (FRS 2004). Poor visibility caused by tidal currents has been shown to reduce the effective water depth in which herring larvae can visually feed (Fox *et al* 1999). Feeding and growth are very low during winter.

Herring is the second most abundant pelagic species landed in the North Sea. The North Atlantic stock collapsed in the 1960's but partially recovered following a ban on fishing in the 1970's and again in the 1990's (Clarke 2003). Stocks are still under pressure and may never recover to their former abundance (Dipper 2001). At the moment measures are in place to ensure the stock levels are above a minimum and the stock is defined by the International Council for the Exploration of the SEA (ICES) as within safe biological limits in terms of current fishing effort (Clarke 2003). Herring are fished during the winter in the Thames (Gray 1995). The Thames Blackwater fishery is accredited by the Marine Stewardship Council as an environmentally responsible fishery (Clarke 2003).

As well as being commercially fished, herring is also an important food species for seabirds, dolphins and large fish (Dipper 2001).

Habitat & behaviour

Herring occur at depths down to 250 m. During daytime, herring shoals remain close to the sea bottom or in deep water. As herring are visual feeders, light is an important factor in controlling their vertical distribution. At dusk they move toward the surface and disperse over a wide area. Herring have excellent hearing, and a very fast escape response, which acts as an anti-predator device (Froese & Pauly 2004).

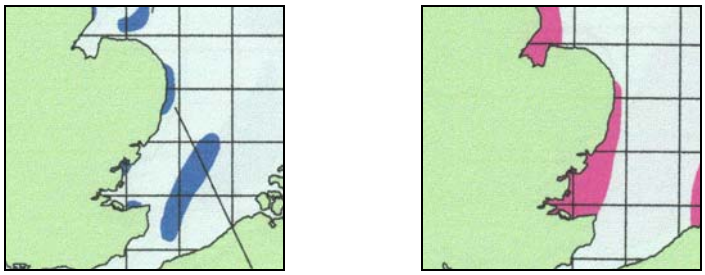
When the young herring reach about 5 cm in length they form large shoals often mixed with sprats, collectively called whitebait. They enter shallow coastal water and large estuaries where they remain for about 6 months. After this time, they appear to scatter into deeper water and do not join the main shoals until they are sexually mature, at about 3-4 years old (Lythgoe & Lythgoe 1971, FRS 2004). Adult shoals generally occur further offshore.

Distribution and abundance within the Thames Estuary:

Herring is abundant and widely distributed all around Britain (Dipper 2001).

The localised stock of Thames Estuary herring are found in the study area throughout the year although there are some movements up and down the east Anglian and Kent coastlines (Wood 1981). The area is both a spawning ground and nursery area (Coull *et al* 1998) (Figure 1).

Figure 1. Herring spawning and nursery areas around the Thames estuary (after Coull *et al* 1998)



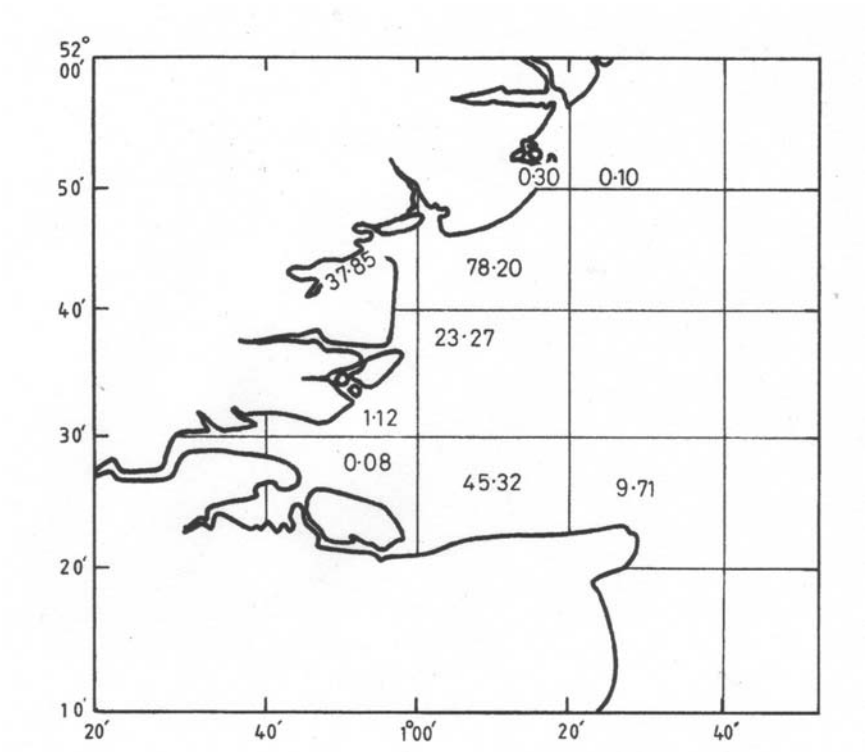
Spawning areas **Nursery areas**

Each spring herring spawn on a gravel bank (Eagle Bank) at the mouth of the Blackwater estuary and also in Herne Bay on the Kent coast. Tagging studies have shown that 71 % of the stock spawn on the Eagle Bank and 29 % off the Kent coast (Wood 1981). After hatching, the larvae can be caught around the Eagle Bank for several months (Fox & Aldridge 2000). The young herring mostly stay in the Thames Estuary and since the river has been cleaned up, it is much more common in the lower reaches of the Thames. They are common in the west Thurrock power station cooling water and also in the Southend whitebait fishery (Wood 1981).

In a study of the herring in the Thurrock power station in the Thames estuary, regular patterns of seasonal abundance were recorded. Most herring were juvenile and had a modal length of 8 cm. The growth rate was estimated at 4 cm over the winter in the estuary. Herring entered the middle estuary in large numbers in late August/early September. Peak abundance was recorded between November and March with a decline after this. Herring was the second most abundant species in the study and occurred in 95 % of all samples (Power *et al* 2000*a*).

Wood (1981) also recorded herring migrating into the Thames Estuary from adjacent areas in autumn. During the winter between October and January/early February, adult herring were concentrated within the Thames Estuary in the Middle Deep, South-west Reach, East Swin (or King's channel) and the Wallet. Apart from some herring off the North Foreland, only small numbers were found outside these areas. This is illustrated by fishing effort in the winter 1977/78 (Figure 2). Later, with the onset of spawning, concentrations formed in the spawning areas (Wood 1981).

Figure 2. Distribution of the commercial herring catch, in tonnes per statistical rectangle, for the fishery September 1977 – March 1978 around the Thames estuary (after Wood 1981)



Sprat

Life history

Sprat is one of the smaller members of the herring family. After 1 year, sprats will be c. 10 cm in length and 12-13 cm long when 2 years old. The maximum size is 16.5 cm (Muus 1974). Growth rates can however be very variable. Sprat become sexually mature at 2 years and rarely live for more than five years (Knijn *et al* 1993).

Sprat is particularly abundant around Britain (Lee & Ramster 1981). In the southern North Sea, spawning normally occurs between April and June (Lee & Ramster 1981). The eggs and larvae are planktonic and drift inshore as they develop. Numbers of sprat may vary considerably as a poor spawning season with cold and windy weather has a knock on effect on the population (Muus 1974).

Sprat feed mostly on copepods (Lee & Ramster 1981).

Sprat is targeted by industrial fisheries and used for fishmeal and oil. Young sprats are caught and sold as whitebait. The North Sea stock is thought to be in good condition (Clarke 2003). Sprat are fished in the Thames over the winter (Gray 1995). Sprat is an important prey species for seabirds, marine mammals and larger fish.

Habitat & behaviour

Sprat is a pelagic shoaling species, often found in large shoals in shallow water, close inshore. They frequently enter estuaries, as they are tolerant of low salinity conditions (Wheeler 1969).

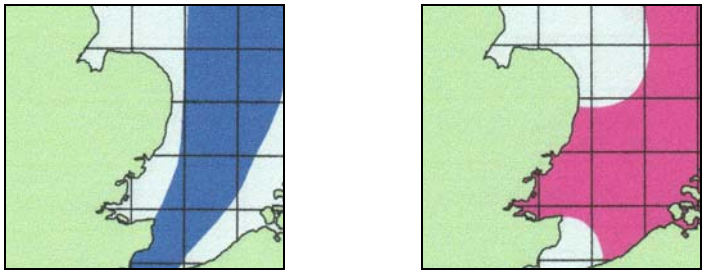
When 4-8 cm long, juveniles are frequently found in coastal waters and estuaries. At this time they form concentrations of whitebait, sometimes with juvenile herring (Lee & Ramster 1981). In summer sprat are found at depths of 10-50 m while in winter they may be found in waters as deep as 150 m. During the day the shoal stays close to the bottom, rising to the surface at night when the shoal breaks up (Muus 1974).

In October or November, when food becomes scarce, sprat stop feeding and live off the fat reserves they have built up over the summer. Large concentrations build up in winter in coastal waters, bays and estuaries. Around February/March, these concentrations disperse and the sprat resume feeding and move to the spawning grounds. Although some sprat spawn in coastal waters, most spawning occurs offshore (Lee & Ramster 1981).

Distribution & abundance within the Thames Estuary

Sprat are abundant in the Thames estuary over the winter, particularly in the outer areas (Power *et al* 2000*a*). Sprat spawn to the east of the study area in the vicinity of the Thanet windfarm. The entire study area is used as a nursery area by sprat (Coull *et al* 1998) (Figure 3).

Figure 3. Sprat spawning and nursery areas around the Thames estuary (after Coull *et al* 1998)



Spawning areas **Nursery areas**

In a study in the middle Thames estuary, sprat were found to enter the estuary in large numbers in late November. Juvenile (0-group) sprat were the dominant age group with a modal length of 7 cm and an estimated 0.33 cm increase of length during estuarine residency. Numbers peaked in January and were lowest in summer. Sprat were the sixth most abundant species in the study and occurred in 99% of the samples (Power *et al* 2000*a*).

The presence of a commercial fishery for sprat in the outer Thames estuary during the winter indicates that this species is abundant in this area at this time of year (Gray 1995).

Cod

Life history

Cod is widely distributed in the waters around Britain (Dipper 2001). Like herring, there are many races of cod, each with their own preferred areas, spawning habits and growth rates. Some races are migratory while others are resident in inshore waters. In European waters, there are a number of reasonably distinct stocks of which the North Sea is one (Muus 1974).

Cod is an average sized gadoid that grows up to c. 120 cm long (Dipper 2001). By the end of the first year, cod will be 18 cm long and by the second will be 36 cm in length (Dipper 2001), thus red-throated divers will be feeding on juvenile fish. Cod reach maturity at about 3 to 4 years of age when about 50 cm in length. They are relatively long living and can reach a maximum of about 20 years of age. (Marine Institute 2001). In the North Sea cod usually live for 6-10 years (Lythgoe & Lythgoe 1971).

Cod are prolific breeders and spawning takes place between February and April at depths of 20-100 m in the North Sea (Lythgoe & Lythgoe 1971). The eggs rise to the surface, typically hatching after 2-3 weeks, depending on water temperature (Muus 1974). The newly hatched young are pelagic and drift towards the nursery areas (Dipper 2001).

Young cod feed mostly on copepods, while adults eat a variety of fish and benthic invertebrates (Dipper 2001).

Cod is an important commercial fish species but has declined drastically due to overfishing and even the current level of fishing is on the limit of what is considered to be safe (CEFAS 2004; Clarke 2003). Cod is fished between October and March in the Thames estuary and the catches fluctuate considerably (Thames Research Forum 2004).

Habitat & behaviour

Cod is found in a variety of habitats from the shore down to 60 m or more (Dipper 2001). Mostly small young fish live close inshore. Adults migrate south in winter to feed and are more likely to be found shallower waters at this time (Dipper 2001). As well as occurring in coastal waters cod may be found down to depths of 500-600 m (Muus 1974).

Cod form compact shoals during the day, usually around 30–80 m off the bottom, spreading out at night (Wheeler 1969).

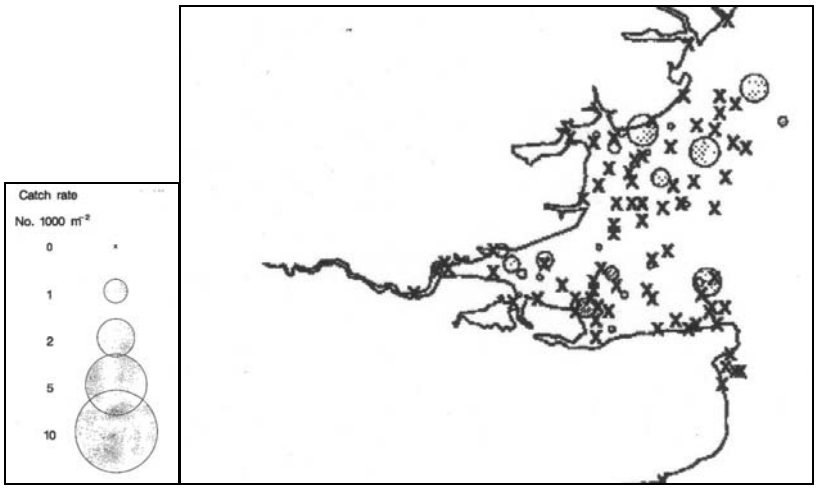
Around summer/autumn time, when juvenile fish are around 3 to 5 months old, they move to the bottom in shallow waters (Knijn *et al* 1993). By the following winter, the young fish are between 13 cm and 26 cm in length and are concentrated in the shallow coastal waters of the eastern North Sea. Cod aged 1 and 2 years old can be found all over the North Sea, although after 3 years they are distributed mainly towards the northern North Sea. (CEFAS 2004).

Adults may migrate distances of up to 200 miles or more to their breeding grounds. During the long spawning and feeding migrations of the adults there is evidence that the shoals travel with suitable currents often in depths of 300–400 m. Juvenile cod, or codling, do not make such extensive migrations, although to the south of their range they approach the coast and move southwards with wintertime cooling of the sea, and make an offshore and northward migration in Spring. (Wheeler 1969).

Distribution & abundance within the Thames Estuary

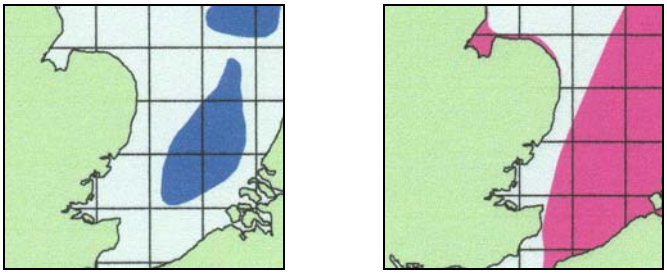
Rogers *et al* (1998) recorded cod in small numbers in the Thames Estuary (Figure 4). Fish were caught at depths of 3-18 m, with c. 35% of fish at 18 m. In another study, cod were recorded infrequently in the middle Thames Estuary Power *et al* (2002b). Cod are known to move into the lower reaches of the Thames in winter (Thames Research Forum 2004).

Figure 4. Cod distribution in the Thames estuary (after Rogers *et al* 1998)



The nearest spawning areas are to the east of the proposed wind farms. The Thanet wind farm site is on the edge of a nursery area for cod (Figure 5) (Coull et al 1998).

Figure 5. Cod spawning and nursery areas around the Thames estuary (after Coull *et al* 1998)



Spawning areas **Nursery areas**

Whiting

Life history

Whiting is one of the most common and familiar fish of the North Atlantic and is particularly common in the North Sea. A member of the cod family, it is usually found in shallower water than its relatives (Marine Institute 2001).

Whiting have a maximum life span of eight years although most fish caught would be three to four years old. Although fast-growing, whiting do not grow very large, reaching an average length of 22 cm when two years old (Marine Institute 2001). Adults would usually grow to 30-40 cm but occasionally reach 70 cm (Dipper 2001).

Whiting spawn throughout their range, with the exception of the extreme north. Spawning usually takes place along the 100 m depth contour between February and June, over a period of up to 8 weeks (Coull et al 1998; Marine Institute 2001; Dipper 2001). The young are planktonic for up to a year, before moving towards the seabed (Dipper 2001).

Whiting are active predators that hunt their prey visually and thus usually feed during the day. While some studies have shown a strong link between whiting and brown shrimp (or Crangon), whiting are generalist feeders, feeding opportunistically on species that are locally abundant (Power et al 2002b). Young whiting feed on shrimp, sandeels, gobies and other small fish. Adult whiting eat larger fish, such as cod, Norway pout and other whiting. (Marine Institute 2001).

Whiting is commercially fished in the North Sea but catches are outside what is considered to be the safe biological limit (CEFAS 2001). In the Thames estuary, whiting is an important bycatch of the cod fishery (Gray 1995). As well as being commercially fished, whiting are also taken by other large fish and by seabirds as they frequently swim near the surface (Dipper 2001).

Habitat & Behaviour

Whiting are usually found at depths of 30-100 m over sandy or muddy ground. (Marine Institute 2001). Adults are found in deeper waters while young fish are found inshore often around wrecks and rocks (Dipper 2001). Juvenile whiting associate with jellyfish, gaining protection from predators by hiding among the jellyfish's stinging tentacles, to which they have some immunity (Marine Institute 2001).

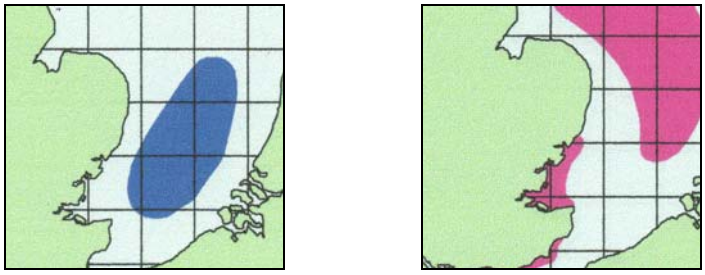
Because whiting spawn throughout their range there is very little migration. Juvenile whiting move inshore and whiting gather in large shoals during spawning and this may involve some movement. (Marine Institute 2001)

Whiting appear to feed most actively at dawn and dusk (Dipper 2001).

Distribution & abundance within the Thames Estuary

Whiting spawn offshore to the east of the study area while the entire area is utilised as a nursery area (Figure 6) (Coull *et al* 1998).

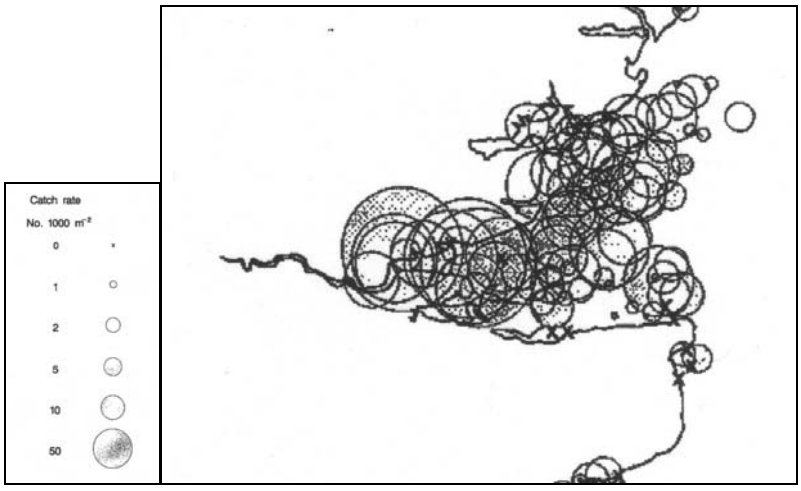
Figure 6. Whiting spawning and nursery areas around the Thames estuary (after Coull *et al* 1998)



Spawning areas **Nursery areas**

Whiting were common and widely distributed during CEFAS surveys in the Thames, recorded between 3 and 25 m deep (Rogers *et al* 1998) (Figure 7). More than 50 % of those caught were in water less than 10 m deep.

Figure 7. Whiting distribution in the Thames estuary (after Rogers *et al* 1998)



In another study in the middle Thames estuary, whiting was ranked as the fifth most abundant fish species sampled out of 11 gadoid species recorded. Most of the whiting recorded were juvenile. Moderate numbers occurred throughout the year but the peak was between September and December. Temperature was the most important determinant of species abundance with numbers increasing as temperature decreased. Salinity was not an important factor in determining whiting abundance (Power et al 2002*b*). Whiting are known to move into the estuary in September, often in large numbers and are fished until February (Thames Research Forum 2004).

Sticklebacks

Life history

Three species may occur in the Thames: the three-spined stickleback, nine-spined stickleback and fifteen spined stickleback.

The three-spined stickleback occurs in both fresh water and seawater (Dipper 2001). They live in shoals most of the year apart from the spawning season in spring. The three-spined stickleback is quite a small fish, usually around 5 cm in length, reaching a maximum of 10 cm. The fifteen-spined stickleback is a larger species, 10-15 cm in length, up to a maximum of 20 cm (Dipper 2001).

Male sticklebacks build nests which they entice females to lay their eggs in. They then guard the eggs until they hatch and tend the newly hatched young for a short time (Dipper 2001).

Habitat & behaviour

Three-spined sticklebacks are more associated with freshwater but a marine form of this species lives in coastal waters, where it occurs among algae near the shore, moving to slightly deeper waters in winter (Rogers *et al* 1998).

The nine-spined stickleback lives mainly in fresh water although sometimes enters brackish water.

The fifteen-spined stickleback is a demersal, non-migratory fish (Oakley 2004). It is found in fully saline coastal waters, usually less than 5 m deep, where it lives in the algal zone singly or in pairs (Rogers *et al* 1998). This species is marine, extending in to brackish water. It is found singly or in pairs confined to weedy shorelines and inshore waters less than 20 m deep.

Distribution & abundance within the Thames Estuary

Few three-spined sticklebacks were recorded in CEFAS surveys in the Thames. 30 % of those caught were in water less than 1 m deep and almost 50 % were at 6 m (Rogers *et al* 1998).

No nine or fifteen-spined sticklebacks were recorded during these surveys. Fifteen-spined sticklebacks are recorded all around the coast of Britain but are uncommon in the south-east (Oakley 2004).

Sandeels

Life history

Sandeels are small, silvery pelagic shoaling fish that feed during the day and at night bury themselves in the sand (Knijn *et al* 1993). They are an abundant and important component of food webs in the North Atlantic as they are a prey species for many larger fish species as well as seabirds and marine mammals. In addition, they are commercially exploited mainly for fishmeal and oil. This fishery is the largest single species fishery in the North Sea, with annual landings in the last decade of around a million tonnes (Knijn *et al* 1993).

In the North Sea, there are many isolated populations of sandeels. Some of these stocks are more sensitive to fishing effort than others as they may have slower growth rates and take longer to mature. Overfishing in Shetland was thought be the cause of breeding failure in seabirds but subsequent research has shown that the cause was not directly caused by the fishery but by natural factors affecting recruitment of sandeels. However the fishery may have had indirect effects by aggravating the stock decline (FRS 2004).

Five species of sandeel are found in the North Sea of which 3 are likely to occur in the Thames study area. These are the two lesser sandeel species, (common and Raitt's sandeels) and the greater sandeel. The two remaining species are generally found further offshore in deeper waters.

Spawning occurs at different times of year, depending on the species. Common sandeels spawns in autumn while the greater sandeel spawns in spring and summer (Wheeler 1969). Most information is available for Raitt's sandeel, which spawns a single batch of eggs between November and February (Coull *et al* 1998). The eggs are deposited on the seabed and hatch after several weeks, usually in February-March. The larvae drift in the currents for one to three months, before settling on the sandy seabed. Average length around this time would be 4 - 5 cm, reaching 5 - 10 cm in length within three months of hatching. Sandeels are comparatively short-lived with a life span of less than 10 years. (FRS 2004)

Sandeels take between one and three years to mature. After 3 years, the common sandeel is about 16 cm and it grows to a maximum of 20 cm. Raitt's sandeel grows up to 24 cm, maturing mainly at the end of the second year. Although this species can live up to 10 years, longevity is usually not more than 3 years because of predation and fishing (Lee & Ramster 1981). Greater sandeel is the largest species, growing up to 40 cm (Miller & Loates 1997). The majority spawn at 2 years and the life expectancy is similar to Raitt's sandeel but the growth rate is faster in the first 2 years. By the age of 3, greater sandeels average 24-25 cm in length which is about the upper size limit for red-throated divers (Cramp and Simmons 1977).

Sandeels feed on plankton, worms, crustaceans and small fish (Dipper 2001).

Habitat & Behaviour

During the active feeding season (April-September) sandeels tend to emerge during daylight hours to forage close to their burrows (FRS 2004). When light levels fall below a certain level, sandeels will burrow into the sand, remaining buried at night and also, it is thought, for much of the time during winter (Lee & Ramster 1981). In addition to burrowing at low light levels, sandeels often swim in a head down position and dive into the sand immediately if there is any danger (Dipper 2001).

Although sandeels are thought to spend most of the winter buried in sand, they have been found in fish stomachs and seal droppings at this time. Alternative hypotheses are that sandeel shoals are more compact during the winter and or that spawning behaviour makes adult fish more difficult to catch (Knijn *et al* 1993).

Research and tagging studies have shown that sandeels live in specific types of sand. This dependence on sandy sediments means that the distribution of juvenile and adult sandeels is restricted by the patchiness of their preferred sandy habitat (FRS 2004).

Raitt's sandeel prefers coarse sand and so its distribution is linked to this sediment type. Dense schools tend to occur on the tops of sand ridges or along the margins of larger sand banks (Lee & Ramster 1981). They are not usually found in waters less than 30m deep. Juveniles are most abundant in the upper 50 m of water but are found down to 150 m (Wheeler 1969). Observations on the availability of Raitt's sandeel to fisheries and their occurrence in sediment suggests that this species rarely emerges from the seabed between September and March, except to spawn.

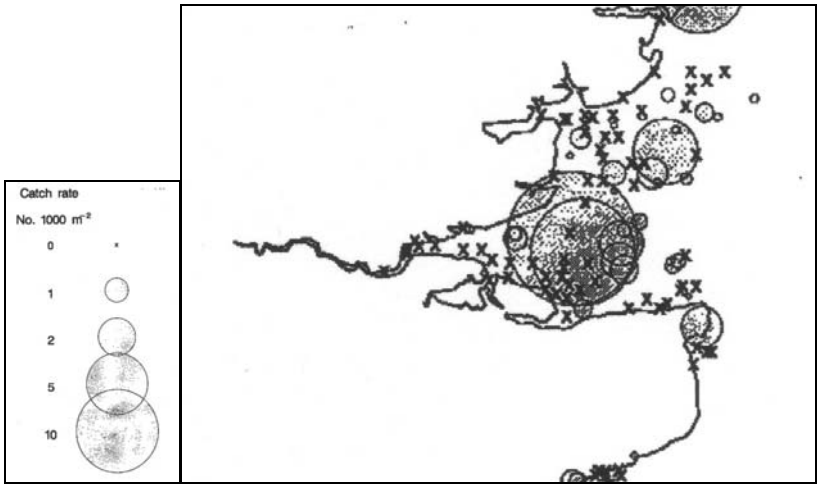
The common sandeel is very common from the mid-tide level of sandy shores down to 30 m, and usually occurs in large shoals (Wheeler 1969). Adults are found at all depths but the larger fish tend to be found nearer the bottom (Wheeler 1969). Common sandeels will bury themselves between 20-50 cm in the sand in winter (Rowley 2004).

The greater sandeel is usually found over or in sand down to about 60 m and occur in deeper water during spring and summer (Miller & Loates 1997, Lythgoe & Lythgoe 1971). Young fish may be found in inshore waters and this species extends down to 150 m (Wheeler 1969). It is found in sand or swimming over sandy bottoms (Wheeler 1969). In summer it is found in shallower water than in winter (Muus 1974).

Distribution & abundance within the Thames Estuary

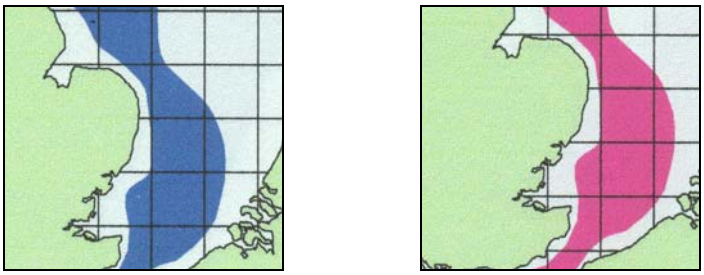
Sandeels were recorded in all years in CEFAS surveys although numbers varied between years (Rogers et al 1998). Highest densities were recorded east of the London Array proposed wind farm with moderate densities within the wind farm area (Figure 8). Sandeels were recorded between 3 and 25 m but were most frequently recorded at 3 m. As sandeels prefer coarse sediments, they are less common in the Thames than in other areas such as the Wash (Rogers *et al* 1998).

Figure 8. Sandeel distribution in the Thames estuary (after Rogers *et al* 1998)



Raitt's sand-eel spawns to the east of the study area between November and February. The same area is also used as a nursery area (Figure 9) (Coull et al 1998).

Figure 9. Raitt's sandeel spawning and nursery areas around the Thames estuary (after Coull *et al* 1998)



Spawning areas **Nursery areas**

Butterfish

Life history

The butterfish is a small eel-like fish which belongs to a group called the Arctic blennies (Dipper 2001). Although it can reach 25 cm in length, it is very slow growing (1-3 cm per year) and usually smaller fish are more common (Dipper 2001). Longevity is thought to be about 10 years.

Spawning occurs in January and February with the eggs deposited in empty shells or between stones. They are guarded by the female, sometimes with the help of the male. The eggs hatch after a month and the larvae are initially planktonic before settling on the seabed.

Butterfish feed on worms, mollusc and small crustaceans and are prey for other fish and seabirds (Dipper 2001).

Habitat & behaviour

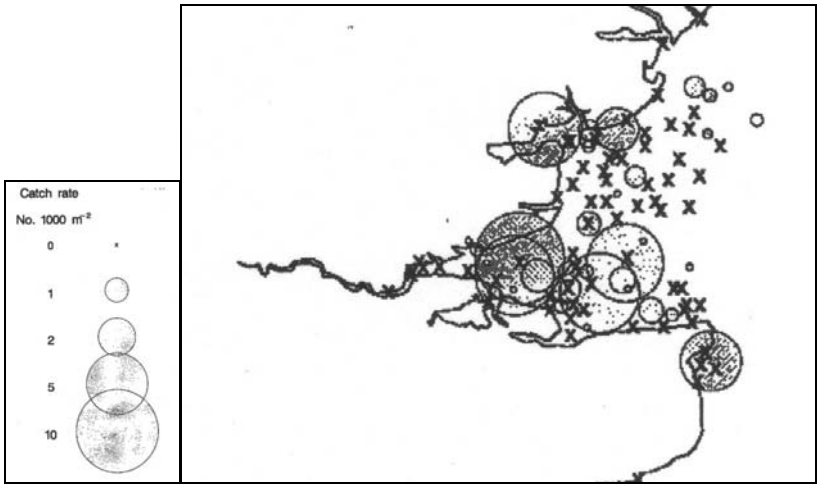
Butterfish are found mostly on the rocky shores among stones and seaweed, although sometimes they are found on sand and mud, hiding in empty shells or between loose pebbles (Dipper 2001).

During CEFAS surveys, butterfish were caught in waters between 4 and 19 m deep with a peak of 35 % at 16 m (Rogers *et al* 1998). They can also be found in deeper water down to 100 m, particularly in winter (Froese & Pauly 2004).

Distribution & abundance within the Thames Estuary

This species is common all round the coast of Britain (Dipper 2001). Butterfish were moderately abundant during CEFAS surveys but were infrequently recorded within the proposed London array wind farm site (Figure 10) (Rogers *et al* 1998).

Figure 10. Butterfish distribution in the Thames estuary (after Rogers *et al* 1998)



Gobies

Life history

Most goby species are small (5-12 cm in length) and live in coastal shallow waters often in great numbers. They form 2 groups according to habitat. Most species live on or near the sea-bed but three genera (*Aphia, Pseudaphyta* and *Crystallogobius)* are pelagic. Up to eight species are likely to occur in the Thames study area (Table 1).

Little is known of the life history of the gobies although they are generally short-lived, and there may be substantial changes in abundance between years.

Three of the goby species likely to occur in the Thames (giant goby, black goby and rock goby) are relatively large, while the other five are small (c. 6 cm). The giant goby is the largest European goby species, growing up to 27 cm in length (Dipper 2001). The black goby grows to a maximum of 18 cm and is c. 15 cm long when 2 years old (Rogers *et al* 1998). Rock gobies grow to 17 cm in length (Dipper 2001).

The two-spotted goby is sexually mature after one year at c. 6 cm long and rarely lives more than two years. The sand goby usually grows to around 6 cm and is sexually mature after 1 year. The very similar common goby is around the same size. Most sand and common gobies only live for a year (Dipper 2001).

Painted gobies live for 1-2 years and most adults are about 6 cm long (Dipper 2001). Painted gobies may be smaller than the preferred prey size of red-throated divers. A study of black-throated divers showed that breeding birds took prey less than 6 cm long when provisioning chicks but preferred larger prey between x and x when they were fishing for themselves (Jackson 2003).

Crystal gobies live for 1 year and reach 4 - 5 cm in size (Wheeler 1969). The transparent goby lives for 1 year and attains a maximum length of 6 cm. Unlike the short life-span of the other goby species, rock gobies are thought to live for up to 10 years (Dipper 2001).

Female gobies lay their eggs in disused mollusc shells or under rocks which are then brooded by the male until they hatch (Dipper 2001). Rock gobies make a nest from sand and shells, two-spotted gobies make a nest in seaweed, while common and sand gobies make an elaborate nest excavating a chamber under an upturned shell (Rogers *et al* 1998, Dipper 2001). In demersal or bottom-living species, the larvae are pelagic at first, before settling on the seabed (Dipper 2001).

The black goby feeds mainly on crustaceans, small fish, molluscs and worms. Common and sand gobies feed mainly on crustaceans. The rock goby has a varied diet including young fish, crustaceans and seaweed. The giant goby also feeds on crustaceans and seaweed. The two-spotted goby feeds on plankton (Dipper 2001).

The common goby probably provides an abundant food supply for seabirds but little study has been done on its predators (Dipper 2001).

Habitat & behaviour

The black goby is found at depths of 1-50 m in muddy and sandy areas particularly among sea grass. It is also found in estuaries as it can tolerate low salinities (Rogers *et al* 1998, Dipper 2001). Rock gobies are found in rocky inshore waters down to about 15m. The rock goby is generally a solitary territorial species. The giant goby is found in rocky shore pools often in brackish water (Dipper 2001).

During CEFAS surveys, the black goby and giant goby were found mostly at depths of 5-8 m, while most rock gobies were between 5-11 m in depth (Rogers *et al* 1998).

Common and sand gobies are found close inshore over sandy or muddy bottoms. Both species tend to move into deeper water in winter (Dipper 2001). The sand goby lives on the bottom at depths of 4 – 200 m and sometimes forms small shoals. In CEFAS surveys, sand gobies were caught between 0 – 24 m and were evenly distributed at all depths (Rogers *et al* 1998). Painted gobies live on coarse bottoms of gravel, shell gravel or sand mixed with shells and stones, often hiding in empty bivalve shells. They are found inshore down to 50 m (Dipper 2001).

The two-spotted goby lives in shallow water in the algal zone and is found down to 20 m. During CEFAS surveys, this species was found in waters less than 6 m deep (Rogers *et al* 2001). It is different to other goby species in that it swims just beneath the surface often in large shoals, hovering above or in seaweeds, and making sudden darting movements to feed (Dipper 2001; Ballerstedt 2003). In captivity, individuals have been observed to bury themselves in the sand at night and they may also do this in the wild (Dipper 2001).

Crystal gobies are a pelagic shoaling species found at depths between 1 and 400 m. The transparent goby is found in dense shoals in shallow waters. This species was recorded by CEFAS off the south coast of England at depths between 3 and 19 m with c. 50 % at 8-9 m (Rogers *et al* 2001).

Distribution & abundance within the Thames Estuary

Three of the relatively large species, the rock goby, black goby and giant goby were found in the Thames during CEFAS surveys (Rogers et al 1998). Rock goby and black goby were uncommon while moderate numbers of giant goby were recorded (Figures 11-13). The black goby and the giant goby have become more abundant in the last 20 years perhaps due to recent increases in water temperature (Rogers *et al* 1998). The giant goby is a rare species and has only been recorded in the south of England (Dipper 2001).

Figure 11. Rock Goby distribution in the Thames estuary (after Rogers *et al* 1998)

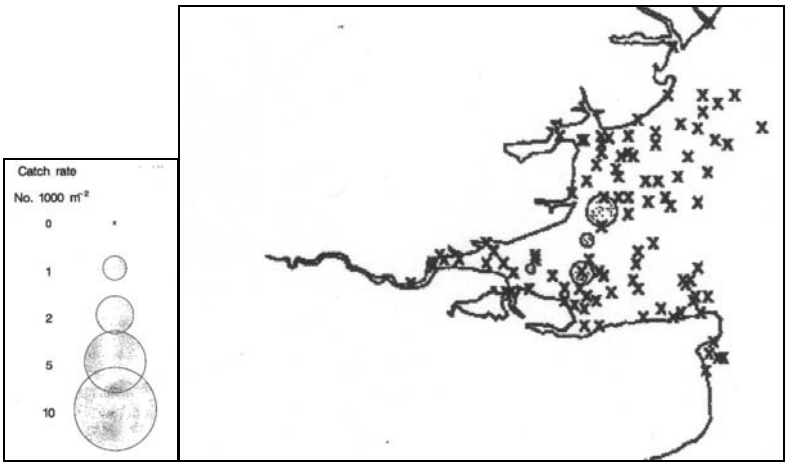


Figure 12. Black Goby distribution in the Thames estuary (after Rogers *et al* 1998)

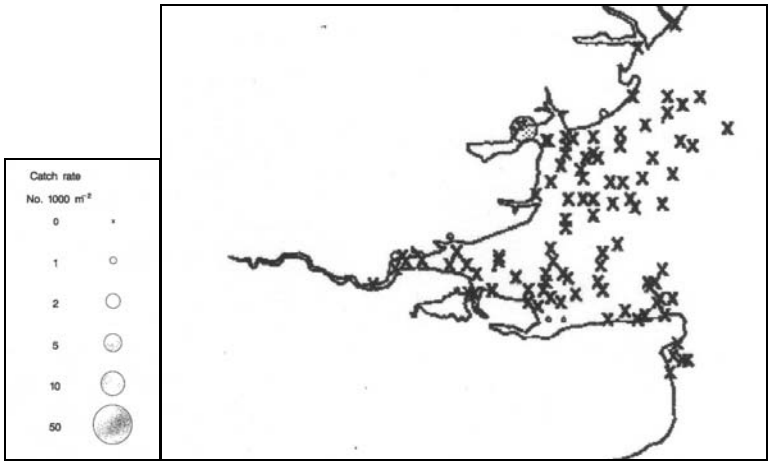
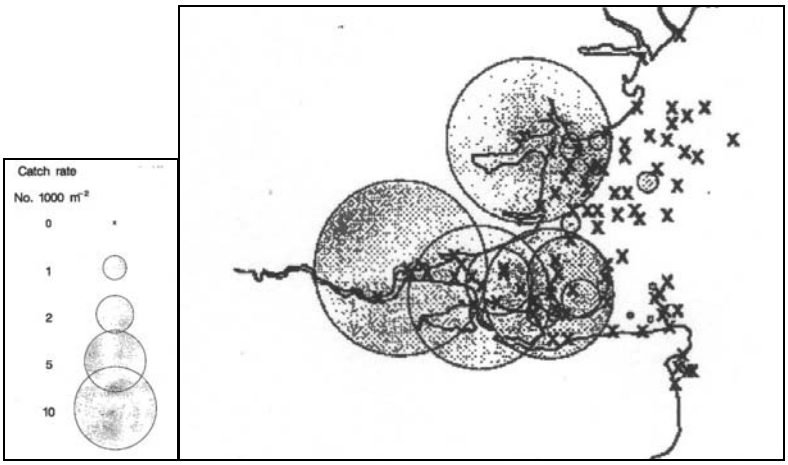


Figure 13. Giant Goby distribution in the Thames estuary (after Rogers *et al* 1998)



Common and sand gobies are both abundant all around the coast of Britain (Dipper 2001). Small sand gobies (*Pomatoschistus* species) were the most abundant species on CEFAS surveys and sometimes were caught in their thousands in a single haul. (Rogers *et al* 1998) (Figure 14). Sand goby was the commonest species and was present in almost all catches during the survey. Two-spotted goby was uncommon in the Thames Estuary (Figure 15).

Crystal gobies were rare while the transparent goby was not recorded in the Thames Estuary (Rogers *et al* 1998). These species could have been under-recorded as they are pelagic and the CEFAS catch methods were aimed at demersal fish species. The transparent goby was however locally abundant in the south-east coast of England during the surveys.

Figure 14. Distribution of sand gobies (*Pomatoschistus* species) **in the Thames estuary** (after Rogers *et al* 1998)

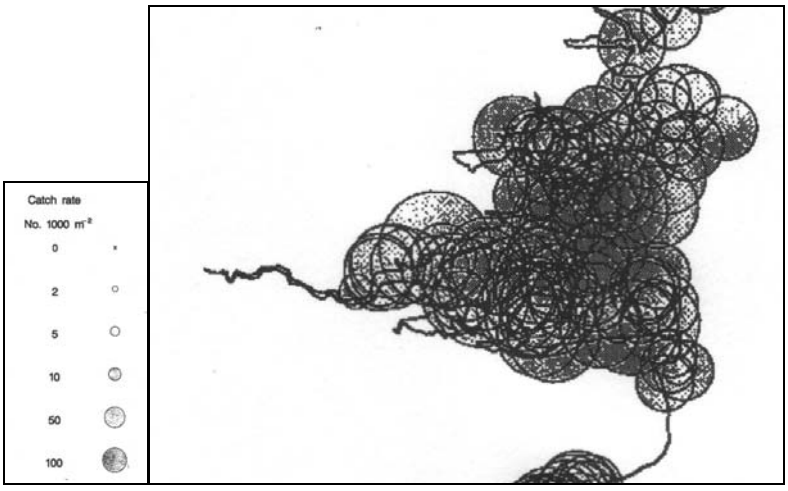
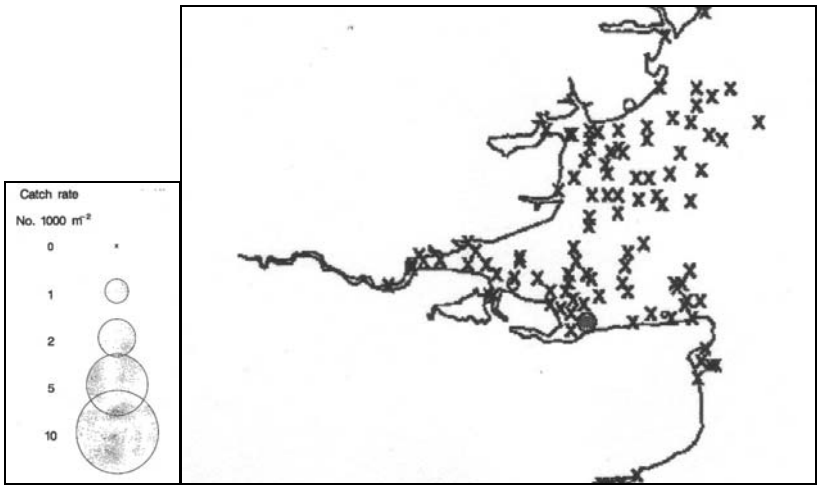


Figure 15. Two-spotted Goby distribution in the Thames estuary (after Rogers *et al* 1998)



Flounder

Life history

The flounder is a right-eyed flatfish similar in appearance to plaice, although it is not as palatable and has limited commercial value. White on the underside, flounder is brownish on the upper surface and can change colours to match its surroundings. It feeds mostly on bottom-dwelling invertebrates.

Flounders can grow up to 50 cm, but individuals over 30 cm are rare (Dipper 2001). In a study in the middle Thames, mainly juvenile or 0-group flounder were recorded, with lengths varying between 3 and 30 cm, and a peak frequency of 4 cm (Power *et al* 2000*b*). In the same study, temperature was the most important determinant of flounder abundance and significant increases in abundance were noted in years with warmer water. Flounder has a wide tolerance of salinity (Dipper 2001).

In spring, adult flounder move further offshore to depths of 35-40 m to spawn. The eggs, which float near the surface, hatch after about a week if the water is a suitable temperature (10° C). Larval flounder are pelagic but gradually become demersal as they take on the adult form, when they are 1.5-3 cm long. Flounder become sexually mature at 3 years in males and 4 years in females (Dipper 2001).

Habitat & behaviour

Flounder are most abundant in and around estuaries, and prefer muddy bottoms although they are also found over sand from the shore down to c.50 m (Dipper 2001). They are often found in freshwater although they breed in the sea.

In the first year, young flounder are mostly found in very shallow water close inshore. Flounders spend most of the day buried in the sediment and so are not easy to spot. At night they feed actively in shallow water moving into the shore at high tide and retreating as the tide goes out (Dipper 2001).

Distribution & abundance in the Thames Estuary

Flounder were abundant in the west of the study area and recorded in small numbers in the proposed wind farm area during CEFAS surveys (Figure 16). They were caught at depths between 3 and 17 m with c. 50 % in waters less than 10 m deep (Rogers *et al* 1998).

In another study in the middle Thames estuary, flounder was the most numerous flatfish species and was recorded in all samples (Power *et al* 2000*b*). Large numbers occurred throughout the year with a peak of abundance in July associated with the inshore migration of juveniles. Abundances declined over the autumn as flounder migrated offshore for over-wintering.

Figure 16. Flounder distribution in the Thames estuary (after Rogers *et al* 1998)

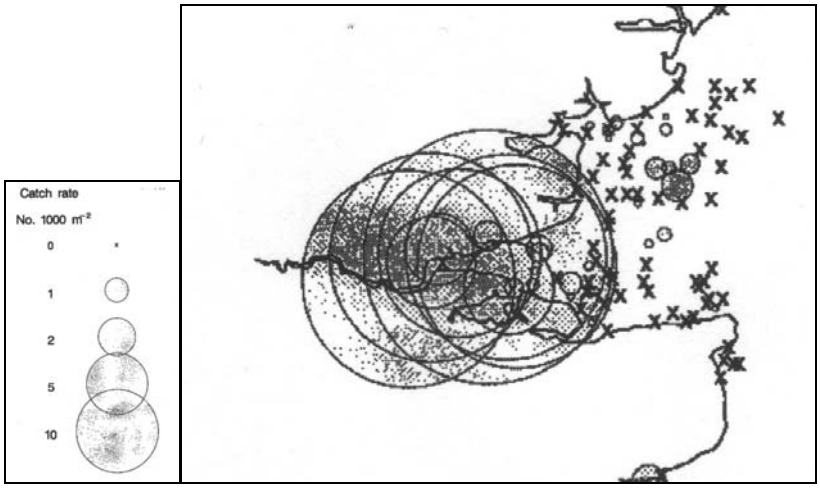
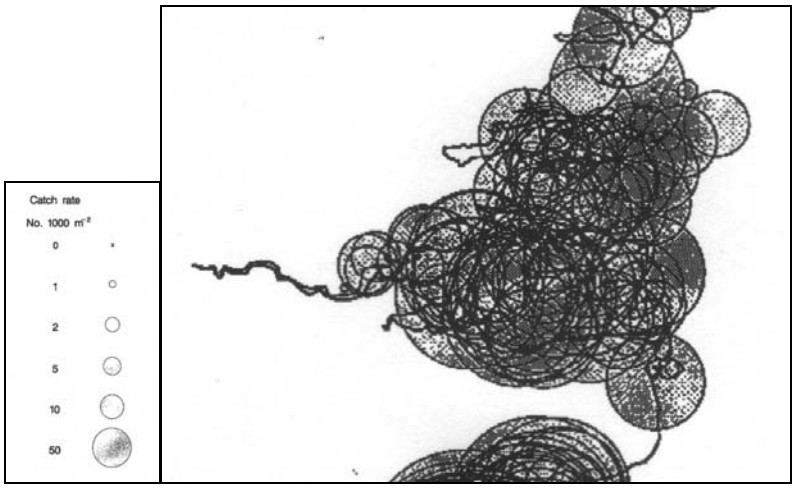


Figure 17. Dab distribution in the Thames estuary (after Rogers *et al* 1998)



Dab

Life history

The dab is a small right-eyed flatfish which usually grows to about 25 cm long. A study in the middle Thames estuary recorded mostly juvenile dab varying in length between 3 and 21 cm, peaking at 4 cm (Power et al 2000*b*). The species is very common, particularly in the North Sea. Although quite a small fish, dab has a good flavour and is moderately important commercially. Dab feeds on a wide range of benthic invertebrates (Dipper 2001).

Males start breeding when 2 years old and females after three years. Dab can live for up to 12 years. Spawning is temperature dependent and takes place in spring and early summer in Britain. The eggs float near the surface and hatch after within a week or two. As the young larvae metamorphose at a length of c.1.5 cm, they move down to the seabed (Dipper 2001).

Habitat & behaviour

Dab live in sandy areas from the shore down to 150 m or more but are most common between 20 – 40 m (Dipper 2001). Dab were found at depths of 0 - 19 m during CEFAS surveys in the Thames estuary (Rogers *et al* 1998). Juvenile dab are abundant in sandy coastal waters and are often associated with juvenile plaice (Rogers *et al* 1998). They are usually found in water less than 1 m deep. During the summer months, adults migrate inshore from deeper water (Dipper 2001).

Like flounder, dab is mostly active at night. Dab has a characteristic feeding method whereby it raises its head and the front part of it's body over a suitable site and waits for an opportunity to pounce on a worm or shellfish siphon (Dipper 2001).

Distribution & abundance in the Thames Estuary

During CEFAS surveys, dab were abundant throughout the Thames Estuary study area (Rogers *et al* 1998) (Figure 17). In a study in the middle Thames, dab occurred in small numbers in almost 50 % of the samples. Very low numbers occurred for most of the year with the exception of September to December when large numbers of juvenile fish used the estuary as a nursery area (Power et al 2000*b*).

Long Rough Dab

Life history

The long rough dab is a brown flatfish that grows up to 50 cm (Miller & Loates 1997). Longevity is a maximum of 19 years but is rarely more than 10 years or 40 cm (Muus 1974). When the fish are c.25 cm long at 2-3 years of age, they become sexually mature (Muus 1974).

Spawning occurs between January and May in the North Sea. The eggs float in the water column and the larvae are also pelagic for a time. Before metamorphosis is complete, they move down to the seabed in depths of 40 to 100 m (Muus 1974).

In the North Sea, the long rough dab feeds throughout the year with a definite peak from April till August (Ntiba & Harding 1993). It feeds mostly on brittle stars, urchins and crustaceans (Miller & Loates 1997).

Long rough dab forms part of the bycatch of trawl and long line fisheries but is discarded because of its poor quality, watery flesh (Muus 1974).

Habitat & behaviour

Long rough dab live on sandy or muddy bottoms and are tolerant of the low salinity in estuaries. They are found in a very wide depth range, from the shore down to 400 m (Lythgoe & Lythgoe 1971).

Distribution & abundance in the Thames Estuary

This species is found right around Britain (Miller & Loates 1997). Long rough dab was rare in the Thames Estuary study area during CEFAS surveys (Rogers *et al* 1998).

5. Discussion

Few studies have been conducted on the diet of red-throated divers outside the breeding season. Fish species which have been recorded as prey items in marine waters are listed in Cramp & Simmons (1977) and Durinck *et al* (1994). Of these, cod, herring, sprat and whiting were the most important prey species by weight.

Madsen (1957, in Durinck *et al* 1994) found cod was the most important prey species by weight followed by gobies and herring. Durinck *et al* (1994) found herring, sprat and whiting were the most important by weight.

Depths of red-throated divers dives have been recorded from 2-9 m (Cramp & Simmons 1977). The main areas for red-throated divers in the proposed wind farm study area correspond with these depths (Appendix A).

This review included all known prey species likely to occur in the Thames Estuary. The importance of each prey species or species group is now examined in the context of the Thames Estuary.

Herring

The Thames estuary herring is likely to form a major part of the diet of the red-throated diver. It is an ideal prey as it is plentiful during the winter and being smaller in size than the Atlantic herring found in the North Sea, the divers can exploit both young and adult fish up to about 4 years of age (c. 25 cm). One of the areas where higher numbers of divers were recorded on aerial surveys (Appendix A), southwest of the proposed London Array wind farm, is an area where herring are known to concentrate in winter (Figure 2).

Sprat

Sprat are also likely to be an important prey species due to their size (maximum size 16.5 cm) and abundance in the Thames estuary over the winter particularly in the outer areas where there is a fishery during the winter (Gray 1995).

Cod

While studies elsewhere showed cod to be an important prey item, numbers in the Thames Estuary may not be overly abundant and in this case cod may not prove to be a major food source. Only young fish would be of suitable size for red-throated divers.

Whiting

The Thames Estuary is a nursery area for whiting where it is common and widely distributed. While moderate numbers are recorded all year round peak numbers of young fish are found between September and December (Power et al 2002*b*). In addition large numbers of adult whiting are present in the study area over the winter months when they are commercially fished.

Previous studies elsewhere in the North Sea have found whiting to be an important prey species and it is likely whiting are an important prey item for red-throated divers in the Thames.

Sticklebacks

The three-spined and fifteen-spined sticklebacks are both likely to occur in the study area, although neither are thought likely to be an important component in the red-throated diver diet. Whilst a profitable size for divers, fifteen-spined sticklebacks do not form shoals and so are unlikely to be responsible for large densities of divers. Few three-spined sticklebacks were recorded in CEFAS surveys and their inshore distribution means they are unlikely to account for the large concentrations of divers further offshore (Appendix A).

Sandeels

Sandeels are important in the food web in summer, as they are a prey species for many seabirds, fish and marine mammals. However during the winter they are not thought to be very active and spend most of the time buried in the substrate. The limited available information on their winter behaviour indicates that they would not be a regular food source of divers over the winter period due to their apparent reduced availability.

Butterfish

Butterfish occur in the study area and are likely to be taken by divers. During CEFAS surveys, however, they were infrequently recorded in the proposed London Array wind farm area and thus are not likely to account for the recorded diver concentrations.

Gobies

Of the goby species that occur in the Thames Estuary, the sand goby is most likely to be an important prey species for red-throated divers with other species taken opportunistically. This species forms shoals and is common throughout the study area being the most abundant species recorded on CEFAS surveys (Figure 14).

Flounder

Flounder is probably the most numerous flatfish in the Thames estuary and may be a common prey item of divers.

Dab

Large numbers of juvenile dab are found between September and December in the Thames Estuary, which is a nursery area for this species. As dab is quite a small fish, the adults are also a suitable size for divers. It is likely that dab form part of the diver diet in the study area.

Long rough dab

This species was rare during CEFAS surveys in the Thames Estuary indicating it may not be a prominent prey item for divers.

6. Conclusions

Many of the species considered in this review utilise the Thames estuary as a nursery and over-wintering area. The available information on these species and their distribution suggests that the chief prey items of red-throated divers in the Thames Estuary during the winter are likely to be herring and sprat. In addition sand gobies, whiting and flatfish such as flounder and dab may also be important. This is similar to the Danish study where herring, sprat and whiting were the most important species by weight (Durinck *et al* 1994).

Around Britain, sprat and herring are very important species in the inshore fish community by weight and number caught, with sprat ranking as the first and herring the third most numerous species (Henderson 1988, in Power *et al* 2000a).

In a study in the middle Thames Estuary, herring and sprat were the second and sixth most abundant species respectively (Power *et al* 2000a). Herring may have been more numerous as there is a herring spawning ground in the adjacent Blackwater Estuary and because sprat tend to avoid inner estuary areas. The presence of a commercial fishery for sprat in the outer Thames estuary during the winter indicates that this species is abundant in this area at this time of year (Gray 1995).

In order to determine more precisely what fish species are present in areas where higher numbers of red-throated divers were recorded on aerial surveys (Appendix A), winter fishing surveys should be carried out.

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APPENDIX A

Diver distribution from aerial surveys

Figure 1. Distribution of red-throated divers from all aerial surveys, and location of proposed wind farm