A review of the European flounder *Platichthys flesus* - Biology, Life History and Trends in Population

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Introduction

Under section 153 of the Marine and Coastal Access Act 2009, Inshore Fisheries and Conservation Authorities will be required to consider specific management of fisheries for the Recreational Sea Angling (RSA) sector, representing the first time in British fisheries management where different needs of the fishing sectors must be considered. A key RSA sector species is *Platichthys flesus*, which has seen little ongoing research despite recent interest and continued value to the RSA sector. *Platichthys flesus (L.),* family Pleuronectidae, is one of the most common of the flatfish species found in European waters; known throughout Britain as 'fluke', 'butt' or more commonly as the 'European flounder' (Fig. 1). In Sweden this fish is called 'flundra', apparently referring to its manner of swimming when close to the benthos, from which the English 'flounder' is probably derived. Found primarily in coastal and brackish waters throughout Western Europe, *P. flesus* densities tend to be highest where the benthic substratum is soft, the distribution extending to the freshwater tidal limit, thus, flounder is an important fish species in the estuarine community (Wheeler 1969; Hemmer-Hanson *et al*. 2007). *P. flesus* has received comparatively little study since it does not have the economic importance of other flatfish, such as plaice (*Pleuronectes platessa*) or sole (*Solea solea*); however, *P. flesus* are important as a food in a few parts of Europe, particularly in the Baltic and Danish waters. The recorded UK catch is very small (<5 tonnes for ESFJC district in 2009, MMO) mostly caught incidentally while fishing for other demersal species, and subsequently used as pot-bait. However, for decades it has been considered a popular sport fish, due to its availability in inshore waters, and readiness to take bait. Wheeler (1969) gave an early detailed description of *P. flesus* biology and identification, which is still useful today. This literature review will appraise the current state of knowledge about this species; highlighting the key biological and life history traits of the species, whilst also noting any inter-annual or seasonal abundance trends of *P.flesus,* using existing scientific papers in peer reviewed journals, and other existing data; this review will also include any traits, behaviours, or impacts that are relevant to the district.

Biology & Identification (Fig.1)

One prominent distinction between *P. flesus* and other flatfish is the presence of finely toothed or notched tubercles between the rays of both the anal and dorsal fins; and along the lateral line, which slightly curves over the pectoral fin. The numerous tubercles are also arranged in two lines, one above and one below the lateral line throughout. The rest of the body is smooth and the scales and mouth are relatively small, with a single row of small numerous teeth in each jaw. The colour of *P. flesus* is variable shades of mottled brown, apparently influenced but not controlled by the nature of the substratum on which they are situated; the fins are generally a lighter shade than the body,

but colouration is variable. Many individuals have reddish spots on the upper surface, but not as bright as those in the plaice; the side with no eyes is a plain white and slightly opaque (Wheeler 1969; Summers 1979; Cooper & Chapleau 1998). Different colour morphs of the *P. flesus* are more common than those of other flatfish including individuals: without any colour on either side (albino variety); coloured on both sides; and with both eyes and colour on the left side instead of the right (Wheeler 1969). However, the roughness of the lateral line in the *P. flesus* and the smoothness in related flatfish is the distinguishing feature.

Fig. 1 Photograph of adult *P. flesus,* next to 12cm ruler. (P.K. Karachle, V.S. Karpouzi, D. Moutopoulos & K.I. Stergiou) (Fishbase.org).

Feeding

The typical *P. flesus* feeding behaviour includes entering the intertidal zone with the incoming tide and feeding heavily during high tide. Fully developed *P. flesus* feed upon a variety of infaunal groups including bivalves (cockles and mussels), polychaetes, crustaceans (crabs and shrimps), and small fishes (Summers 1979; Summers 1980; Pihl 1982; Westberg 1997). *P. flesus* feed during daylight hours, locating their prey visually; mobile prey is actively selected (De Groot, 1971). This is certainly the case for adult flounder, although under lab conditions when faced with equal amounts of active prey (*Bathyporeia pilosa)* and sedentary prey (*Macoma balthica),* juvenile *P. flesus* may favour the latter (Mattila *et al.* 1998). This preference is particularly noticeable when prey availability is reduced; active and sedentary prey may be consumed in equal numbers when offered separately (Mattila *et al.* 1998), suggesting that juvenile *P. flesus* are able to catch both types of prey species with similar efficiency. Sedentary prey may be more easily caught by juvenile *P. flesus* which usually stay and feed close to the bottom (Ansell, 1995). The average size of *Macoma* eaten is also somewhat smaller than the average size of *Bathyporeia*, which may have made *Macoma* a more easily handled and easily digestible prey item for juvenile flounder (Aarnio & Bonsdorff, 1997). The most common food sources of juvenile *P. flesus* include copepods, ostracods, small larvae (Aarnio *et al.* 1996), and cropped bivalve siphons (Ansell & Trevalllion 1967; de Vlas 1979). The ontogenetic shift that occurs during a flounder's lifecycle divides the population into ecologically distinct stages (Olson, 1996) inducing a noticeable shift from a diet comprised largely of meiofauna to that of predominantly macrofauna; consequently the benthic feeding stage in juvenile *P. flesus* decreases dietary competition between flounders of different size classes (see Aarnio *et al.* 1996, for study of *P. flesus* dietary composition).

Behaviour

P. flesus are generally most common within 50 m of the shore, but the distribution may be local within specific areas. It predominantly resides in estuaries and other low-salinity waters; *P. flesus* lives and thrives when resident in either the sea, or brackish water, and is the only European flatfish to penetrate further into estuaries and able to live in freshwater for long periods (Summers 1979; Hemmer-Hanson *et al.* 2007). Although frequently found in freshwater it cannot spawn there as the eggs will not develop, and must eventually return to the sea; *P. flesus* have been recorded to migrate vast distances, although rarely over deep seas (Aro 1989) and average annual migration distances are <32 km (Summers 1969). The migration to deeper water (20-50m) which precedes breeding is primarily undertaken in January and February; February to June being the overall spawning period. The eggs are approximately 1mm in diameter and depending on ambient ocean temperatures take about a week to hatch (at 12°C). *P. flesus* are broadcast spawners, meaning the eggs float to the surface, where they are fertilised, but sink as development occurs, eventually hatching out at lengths less than 3mm. If possible large parts of the settling *P. flesus* population may migrate to fresh water (Berghahn 1984), with only part of the population remaining in the estuary. A metamorphosis into the familiar flatfish form occurs at a length of approximately 10-15 mm and hereafter is generally demersal in habit (Nichols 1971; Russell 1976). Growth thereafter is dependent on environmental factors, but in general they reach an average 80 mm after the first year, 140 mm after year two, 190 mm after year three and 240 mm at their fourth year (de Vlas 1979; Summers 1980). Males reach sexual maturity at approximately 110 mm (2-3 years), and females at 170 mm (Summers 1979; Bos 1999; Drevs *et al.* 1999); however, age at maturity will almost certainly differ between populations, particularly those with decreased numbers or those heavily fished. After spawning many 'spents' (post-spawning adults) will return inshore in summer where intensive feeding takes place in the warmer months; feeding may cease during winter. *P. flesus* show different life-history strategies in different parts of their distribution, indicating genetic divergences between populations (Solemdal 1973; Aro 1989; Drevs. *et al*. 1999; Nissling *et al*. 2002); for example, while in general *P. flesus* spawns pelagic eggs at off-shore spawning grounds, a population in the Baltic Sea has adapted to the brackish environment by spawning smaller and denser benthic eggs nearer the coast, thus, avoiding exposure to anoxic conditions in the deeper parts of the Baltic Sea. The life history of *P. flesus* also allows for the study of the effect of geographical distance on genetic structuring; adult *P. flesus* are relatively site-attached and primarily only migrate between local feeding and spawning grounds (Aro 1983; Aro 1989). Eggs are only pelagic for a few weeks (Russell 1976) and the larvae can utilise estuarine currents for selective tidal stream transport (Campos 1994; Bos 1999) enabling them to reach the nursery grounds even before metamorphosis; juveniles remain resident in brackish or freshwater. The potential lifetime dispersal of a single individual does not correlate with the full distributional area of the species; this along with current systems and bathymetric features affects the population structure, creating genetic divergences due to geographical and physical distribution (Florin & Hoglund 2008).

Distribution and Population Trends

The coastal relatively site-attached nature (Aro 1989), in conjunction with the life history of the species, leads to populations becoming isolated (Hemmer-Hanson *et al.* 2007 and Borsa *et al.* 1997 described a pattern of isolation by distance). Several spawning populations have been studied in the

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North Sea, where they overlap with those of *P. platessa* (Harding *et al.* 1987); the species are particularly common in the southern and eastern coastal North Sea (Fig. 2).

The immigration of *P. flesus* post-larvae (<8 mm) may start in late April-early May, one month after that of the plaice, but some records suggest young *P. flesus* have been caught in estuaries as early as January and February (Rajuddin 1997), with peak numbers during June and July. It is difficult to know if different observed times of larval immigration are due to the study of differing *P. flesus* populations or the use of differing methodologies, particularly mesh size and date of study. There is also increasing evidence that with increasing ocean temperatures, *P. flesus* migrations are occurring earlier (Sims *et al.* 2004; Southward *et al.* 2005; Parmesan 2006), although it is likely that day length is the predominant factor (N Polunin pers. comms.). The large variation in the size of juvenile *P. flesus* found in estuaries indicates that immigration is either in a series of waves (suggesting several short spawning periods) or is staggered due to fish arriving from different spawning sites and the delay is a factor of distance travelled, suggesting one extended spawning period (Johnston 1981; Weatherley 1989; Rajuddin 1997; S Colclough pers. comms.); towards the end of May the immigration decreases, influenced largely by increased crustacean (*Crangon crangon*) and coelenterate predation (such as the ctenophore, *Pleurobrachia pileus* and the scyphomedusa, *Aurelia aurjta*) (Van Der Veer 1985; Colclough *et al.* 2002). This means the flounder larval immigration process previously thought to be restricted to little more than a month may extend over four months or more.
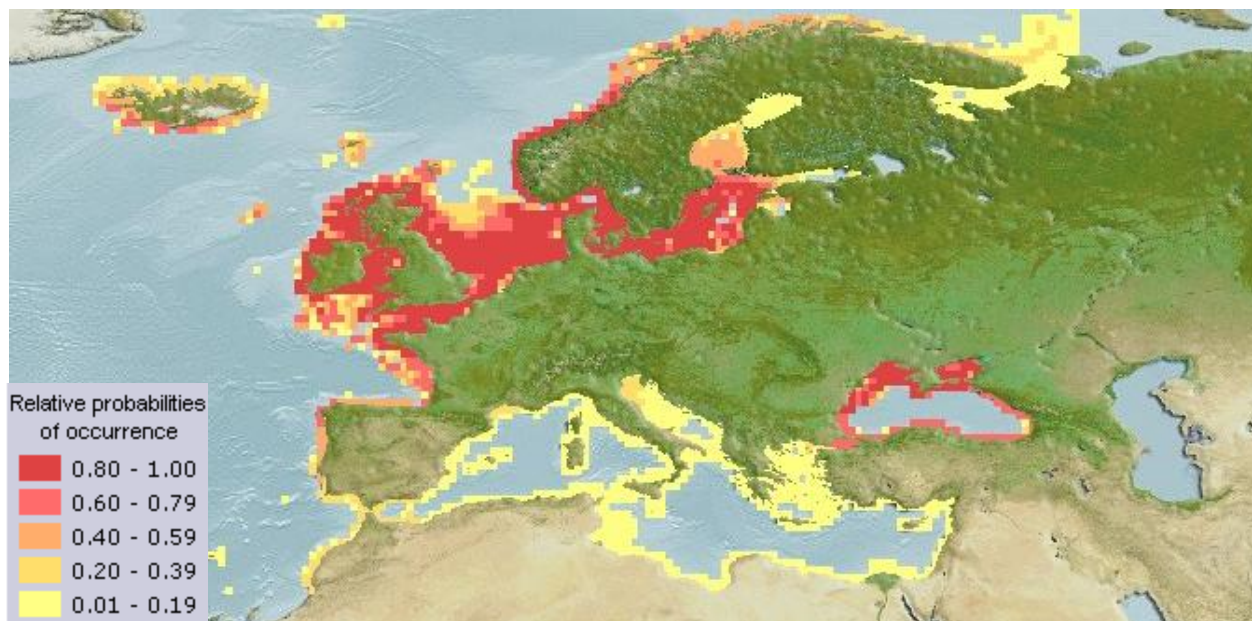

Fig. 2 Diagrammatic map of the native distribution of *Platichthys flesus*. Also introduced via ballast waters into the USA and Canada (Fishbase.org).

In the Ythan estuary (Scotland), 0 group *P. flesus* did not appear in hand and tidal net samples until May and June at lengths of between 20-30 mm (Summers 1979). Smallest juveniles recorded were 20mm meaning <8 mm larvae were undoubtedly missed due to inadequate methodology. Despite the recent improvements of estuarine study techniques, relatively little is still known about the process of larval settling in *P. flesus*; laboratory observations suggest that as in *P. platessa* the search for food is the key factor, but substrate composition has an overriding influence (Creutzberg *et al.* 1978; Kerstan 1991; Van der Veer *et al.* 1991).
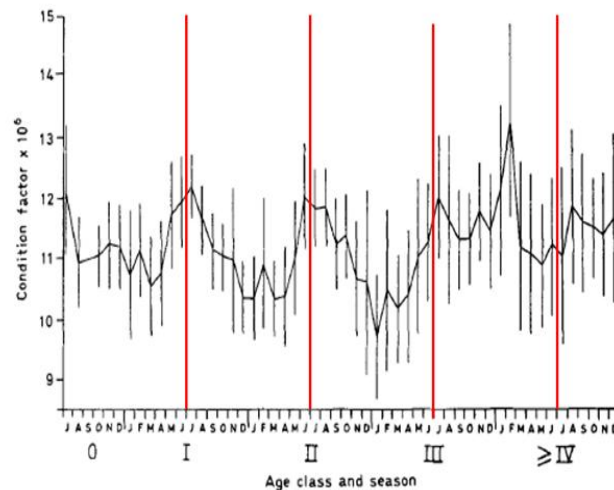
Fig. 3 Fluctuations in condition factor (weight/length[3]) of the age classes of flounder, age classes are born in the same breeding season, i.e. age class II are all two seasons old. The red lines added indicate the seasons i.e. the return of spents and 0 group flounder, which in this study was recorded as June, but more likely to be May (Summers 1979).

In the Ythan, *P. flesus* body condition varies seasonally (Fig. 3), this is echoed by observed spawning seasons, i.e. when condition factor is highest, for age class III (age at sexual maturity), in February, this is also the period that a seaward emigration of spawning flounder is observed . Summers (1979) detected emigration via tag and release methods conducted during April and May 1971. Of the 1,120 *P. flesus* tagged, 13 were recaptured at sea (between 215 mm and 400 mm long; only older groups captured due to commercial fishing mesh size restrictions). Some recaptures in July showed an emigration of older fish during summer months, others during winter when mature *P. flesus* are known to go to sea to spawn. In NE Scotland, numbers of flounder <55mm long decline rapidly in July-August (Fig. 4) and abundances vary seasonally (Fig.5).
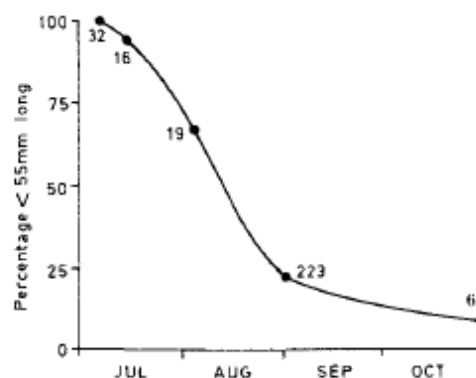

Fig. 4 Graph showing estimated percentage of 0 group flounder <55mm in length in samples from the population (Summers 1979).

A large influx of *P. flesus* into the estuaries occurs in April, reaching summer peaks 50-100 times that of the winter low. Numbers decline from October onwards and the population was smallest from January to March. The fall in numbers during November and February is attributed to seaward migration. Summers (1979) found that four migrations influenced the alterations in size and structure of the population of the Ythan estuary; winter emigration of mature spawning *P. flesus*, the spring (April and May) immigration of immature and spent fish; summer immigration of 0 group fish (late June/early July; however, recent improvements in technique suggest this occurs earlier); and the winter emigration of all age groups leaving a small estuarine population of mainly 0 group and maturing fish.

Information on population dynamics and distribution of *P. flesus* is scarce; estuaries and inshore fisheries have been poorly studied, most recent work being conducted via postgraduate studies, power station cooling water intake screens, and selective beam trawling, across only a couple of regions. Past methods of sampling have relied on individual methods, and thus, do not offer an overall representation of the estuarine community or population dynamics, changes in sampling to cater for seasonality is also often overlooked in estuarine monitoring. Colclough *et al.* (2002) describe a standard shore-based multi-method fish survey programme, a unique, holistic approach to estuarine management later considered an example of European best practice in the field (Hemingway & Elliott 2002), and filling gaps left by previous patchy non-qualitative data (see Coates *et al.* 2007, for use of multi-metric fish index for the Water Framework Directive). With increased improvements in sampling technique comes a greater understanding of estuarine fish populations dynamics.

These techniques have shown that 0-group *P. flesus* enter the estuarine system at a much smaller size than originally thought (<8mm), in the fringes of the estuary, using selective tidal stream transport (Jager 1999) they travel far upstream (unless prevented by anthropogenic obstructions). Shallow waters offer the advantage of higher temperatures, lower risk of predation, abundant food source, appropriate substrate, and less tidal influence. The 1+ *P. flesus* year group do not travel as far upstream as the 0-group, whereas the adult *P. flesus* inhabit the mid-lower estuary, but their distribution is much patchier than that of juvenile *P. flesus* (S Colclough pers. comm.).
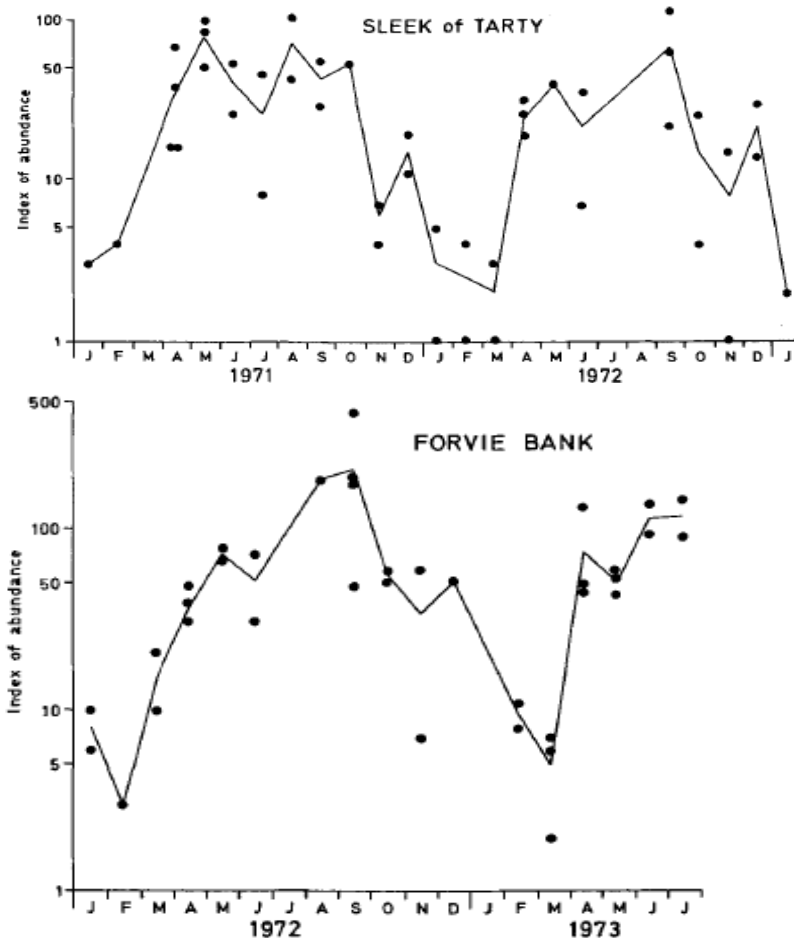

Fig. 5 Indices of flounder population size on the Sleek of Tarty and Forvie Bank. Each point indicates the number caught on one day and one night tide. The line shows the means of the samples obtained each month (Summers 1979).

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Juvenile Development

Habitat quantity is an influence on *P. flesus*, due to its confined distribution and dependence on estuaries and mudflats (Gibson 1994), that are subject to loss of habitat and water quality because of urbanisation and estuarine management. Habitat quantity for flatfish can in theory be easily measured; post-metamorphosis, the fish predominantly inhabit the benthos, rarely leaving the sediment bed. The habitat can therefore be considered two dimensional, and thus easily measured. Habitat quality however, depends on a range of interdependent attributes (Fig. 6), and thus cannot be measured directly, or compared between species.

Flatfish in general, particularly the estuarine based *P. flesus*, rely heavily on sufficient quantity and quality of feeding grounds. The feeding grounds as already stated are mainly intertidal mudflats, estuarine sediments and coastal sediments; therefore it is essential that these habitats are maintained. Estuaries that are ruled by tidal cycles are perhaps more essential to the continued growth and sustainability of *P. flesus*, in part due to the fact that the species can follow the tide, as otherwise it may become easily outcompeted by the numerous demersal/benthic fish species in coastal/oceanic waters.

Concentration of fish into areas of more abundant prey could, if prey was limiting, lead to exploitative competition, density dependent growth effects and possibly even starvation (Branch 1984).
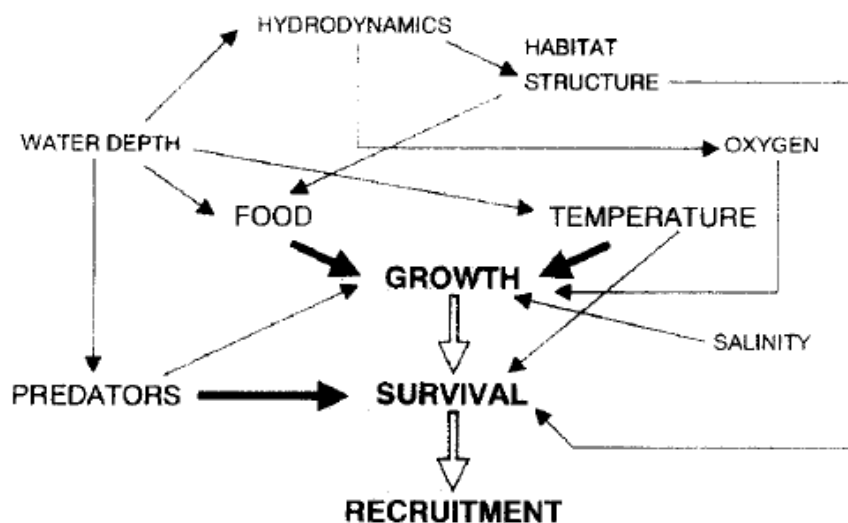

Fig. 6 Diagram illustrating the inter-relationships between factors contributing to habitat quality that influence growth, survival and recruitment of juvenile flatfishes. The size of the lettering and thickness of the arrows indicates the relative importance of the factors. Not all possible inter-relationships are shown. (Gibson 1994).

It remains unclear whether cases of reduced growth are accompanied by decreased survival; indirect evidence of this possibility comes from the observation that starved fish are much more active (Creutzberg *et al.,* 1978; Tanaka *et al.,* 1989; Champalbert *et al.,* 1992) and hence may be more liable to predation; lack of food, leading to poor condition, increases vulnerability to diseases (Vethaak 1992). The concept of environmental limitations gives rise to the idea of 'carrying capacity', although such effects are widely produced experimentally and via models, there is little evidence that carrying capacities of *P. flesus* nurseries are reached in the wild (Gibson 1994).

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Interactions and environmental factors

The following interactions have been highlighted as they are relevant to the ESFJC district. Other interactions such as toxins and harmful substances have been emitted from the review as they are not obvious in the relevant estuaries and inland water bodies.

Predation- observed to be higher on rocky, open coastal areas and lower in sheltered bays; perhaps due to lack of seasonal and motile predators. Cannibalism has been observed in several flatfish, however, this is most likely to occur within year classes, where growth rate is rapid and the settling season long, between year-class cannibalism is only likely where adults over winter on the nursery grounds (Gibson 1994). It was previously believed that *P. flesus* benefit from their larvae settling and metamorphosing in deeper water; therefore the juveniles returning to estuaries tend to be relatively larger than those of other flatfish species, possibly reducing their vulnerability to predation. However, many pre-metamorphosis juvenile *P. flesus* enter the estuarine system very early, and use tidal regimes to move upstream (Gibson 1994; S. Colclough pers. comm.).
If the general rule of decreasing mortality in fish with increasing size applies (Cushing 1974), *P. flesus* will be more vulnerable to predation than *P. platessa* during larval immigration (*P. flesus* 8 mm; *P. platessa* 13 mm). As mentioned previously, there are strong indications that *P. flesus* suffer heavy predation by coelenterates in the plankton (Van der Veer 1985). As soon as the outburst of predatory coelenterates is observed in early May, immigration of both *P. platessa* and *P. flesus* decreases. After settlement, mortality among the 0-group is rather low, except for when a strong and density dependent predation by crustaceans, mainly brown shrimp (*Crangon crangon*) is observed (Van Der Veer & Bergman 1987). Although mortality estimates among the 0-group *P. flesus* might be biased by migration of juvenile *P. flesus* to fresh water. The fact that summer densities stabilised when the *P. flesus* had reached a size of 30mm and were 'safe' from shrimp predation suggests that mortality is the main factor causing the decrease in numbers during summer (Gibson 1994).

Temperature- higher temperatures increase growth rate of juvenile *P. flesus* proportionally (Gibson 1994). Although local alterations in temperature are largely due to managerial control; dredging, may lead to temperate alterations, disposal of thermal waste water etc. Indirect effects of temperature may also occur, such as their effects on the species' predators. There is increasing evidence that *P. flesus* are among some of the first marine fish species to be showing effects from global climate change and increasing sea temperatures (Sims *et al.* 2004; Southward *et al.* 2005; Parmesan 2006), and from a combination of more extreme freshwater flow 'flashes', more extreme droughts and low flows could be affecting inshore environments and thus affecting the flounder larval immigration into our estuaries (S Colclough pers. comms.).

Salinity- also affected by anthropogenic impacts on estuaries, such as dredging, water management, run-off etc. Salinity appears to control distribution and movement (Riley *et al,* 1981; Kerstan, 1991), but has also been shown to impact growth rate (Gutt 1985), but not recruitment. Salinity, however, is often correlated with both sediment structure and temperature so that caution is required when interpreting distribution patterns solely in relation to salinity. Direct effects are most likely during periods of high freshwater discharge in estuaries causing downshore movement or inhibiting entry into the estuary (Rogers *et al.* 1984). Due to the catadromous behaviour of *P. flesus*, this perhaps is not a huge issue, they have been known to survive in freshwater ponds and extend to far reaches of

estuaries beyond the tidal influence. (Made able due to their demersal habit; saline water is densest, so often at the bottom).

Oxygen- in healthy habitats growth is unlikely to be affected by oxygen shortage; however, it appears that of all the physic-chemical variables, dissolved oxygen (DO) appears to be of great significance to fish abundance (Maes *et al*. 2004). Suggesting estuaries of low water quality are at greatest risk of showing negative fish population trends. Furthermore, in shallow estuaries, particularly those with low water quality, or in vegetated bays at night, oxygen depletion may be experienced (Van der Veer & Bergman, 1986; Dorel *et al.* 1991), which could result in temporary emigration to unfavourable habitats in shallower or deeper water, where food densities may be lower or predation risk higher, with consequent effects on growth and survival (Baden *et al.* 1990; Pihl *et al.* 1991). A study on hypoxia in the Northern Baltic Sea (Tallqvist *et al.* 1999) noted cases of oxygen efficiency naturally occurring throughout the summer (due to increased numbers of juveniles and return of spents) and autumn months (due to increased abundance of algal mats). During these periods of sublethal hypoxia, *P. flesus* use these areas as foraging grounds, by preying on infauna, forced to the sediment surface by oxygen depleted conditions (Jørgensen 1980; Pihl *et al.* 1992; 1994). Juvenile flounder utilize these shallow, algal mat habitats during their first few years, feeding on benthic meio and macrofauna (Ostracods; *Hydrobia spp*. and *Macoma balthica*) (Aarnio & Mattila 2000).

Several studies have reported the effects of DO levels on *P. flesus* (Van den Thillart *et al.* 1994; Dalla Via *et al.* 1994; 1997; Moser *et al.* 1996; Tallqvist *et al.* 1999). High concentrations of haemoglobin in the blood of the species suggest their ability to adjust to hypoxic conditions is higher than for other flatfish (Weber & Wilde, 1975). Furthermore, the flounder heart has a high aerobic and anaerobic capacity, suggesting that flounders can tolerate oxygen-poor conditions (Jørgensen & Mustafa 1980 a; 1980 b). Although there is a certain amount of oxygen-poor tolerance, it has been observed that juvenile *P. flesus* do not react to oxygen depletion (Tallqvist *et al.* 1999; S Colclough pers. comm.), hence they are good indicators of estuarine health, as they are often the first species to be observed to die when DO decreases.

Conclusions

Platichthys flesus is an important European estuarine and inshore fish species, its interactions range from freshwater to intertidal mudflats and the coastal sublittoral waters; yet despite this wide ecological value the species remains relatively understudied and undervalued. The conceived lack of economic importance over the past decades has kept this species out of the scrutiny of the scientific community, and there are still many behaviours and annual events in which our understanding is still unclear; such as the spawning process and larval emigration. However, this species has long been valued by the RSA community as a key species. With increased pressure for sustainable inshore fisheries management and with encouragement for increased understanding of our waterways, our knowledge and capabilities to monitor these ecosystems effectively is rising; thus, our ability to manage these previously ignored resources will rise proportionally with continued research and large-timescale monitoring programmes.

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