Southern Inshore Fisheries and Conservation Authority

Net Fishing Byelaw Literature Review

Supporting Document as part of the Inshore Netting Review

Contents

INTRODUCTION TO LITERATURE REVIEW

The aim of the Literature Review is to further inform and support our understandings of (1) likely salmonid and net interactions and (2) the ecological value that an Essential Fish Habit (EFH) may have in terms of providing feeding, nursery or refuge areas for non-salmonid fish species. This information will be used, in combination with site specific evidence to inform the Southern IFCA Netting Review.

This document uses the best available evidence, namely peer reviewed papers and reports.

This Literature Review is to be read in conjunction with the Conservation Assessment Package for the Net Fishing Byelaw and the Site Specific Evidence Packages which have been developed as part of the Southern IFCA Netting Review in order to provide accurate accounts of the current net fishing practices which occur across the Southern IFCA District. For ease, Contextual Discussion Points have been added to this document by the Author in order to provide a contextual summary of local net fishing activity.

SECTION 1: BEHAVIOURAL PATTERNS OF SALMONIDS

1.1 Atlantic Salmon Migration

- Atlantic salmon are known to start entering coastal home waters and rivers from the sea several months prior to spawning although the exact timing of the run will vary between and within populations (Thorstad *et al.,* 2008). The general pattern is for the run to occur from spring to autumn with a tendency for large Multi Sea Winter (MSW) salmon entering the rivers earlier than grilse (one sea winter fish) (Thorstad *et al.,* 2008).
- Upstream migration for adult salmon is reported to take place in three successive phases; (1) a steady progress upriver with periods of active swimming alternating with stationary periods, (2) a long residence period in the river and (3) a short upstream migration just prior to spawning (Okland *et al.,* 2001; Finstad *et al.,* 2005). The fastest migratory speeds have been observed during the first phase of migration (Oakland *et al.,* 2001).
- Okland *et al.* (2001) tagged and released Atlantic salmon and determined that an increase in water discharge was generally associated with increased migration speed once the salmon were already moving but differences in water flow did not affect the days when salmon migrated and when they remained stationary. In addition, increasing air temperature was found to be associated with enhanced migration activity. The study concluded that migration will be influenced by external factors, even in a river without large migration obstacles.
- A similar study was carried out in estuaries on the South coast of the UK where Atlantic salmon were tagged and tracked (Solomon and Sambrook, 2004). The study showed that at times of medium to high freshwater flow to the estuaries, most fish arriving from the sea that were going to enter the river passed through the estuary and into the river with a minimum of delay. However, at times of low freshwater flow most fish arriving from the sea did not pass promptly into fresh water and many remained in the estuary or returned to the sea for periods of up to several months (Solomon and Sambrook, 2004).
- Migratory behaviour and patterns are noted to vary significantly between individuals and between years as environment conditions and parameters such as temperature and water quality will influence river ascent, as has been demonstrated for Atlantic salmon (Jensen *et al.,* 2010).
- Atlantic salmon do not actively feed during their freshwater migration (Brobbel *et al.,* 1996). Fish which are migrating upstream from the sea will have had less starvation time and will be more physiologically robust than those which have spawned and spent a significant

period of time without food. Upstream migrating fish which are caught in a net will therefore have a greater resilience to exhaustion stress and a greater ability to recover, however it is documented that the time taken to recover increases with increasing water temperature (Brobbel *et al.,* 1996).

- Migratory patterns have been noted to be much less varied for Atlantic salmon when compared to sea trout species. Atlantic salmon are seen to relocate and home in on their natal rivers, and even the specific nursery areas where they were smolts, after marine migration (Finstad *et al.,* 2005).

1.2 Atlantic Salmon Orientation In The Water Column

- Adult salmon have been shown to be predominantly surface orientated whilst in inshore areas (between 1.5 to 4m) with individuals undertaking irregular but frequent deep dives of a short duration (Hawkins, *et al.,* 1979). This behaviour is seen to vary between individuals, groups of individuals, locations and times of day (Potter, 1985, Holm, 2006; Hubley *et al.,* 2008; Halttuen *et al.,* 2009, Reddin *et al.,* 2011, Davidson *et al.,* 2013, Godfrey *et al.,* 2014).
- Studies have shown that time spent in the 0-5m zone varied from 60 to 99% for both upstream adults (Holm, 2006; Godfrey *et al.,* 2014) and kelts (Hubley *et al.,* 2008; Halttuen *et al.,* 2009).
- Reddin *et al.* (2011) reported that adult salmon spend greater than 50% of their time in the top 2m.
- These results are supported by a study which showed an average swim depth of 0.5-2.5m (Davidsen *et al.,* 2013) and a study by Potter (1985) who reported salmon staying in less than 4m of water for the majority of the time.
- Deep dives were noted between 30 and 280m (Holm, 2006; Halttuen *et al.,* 2009; Reddin *et al.,* 2011; Davidson *et al.,* 2013; Godfrey *et al.,* 2014).

1.3 Impacts Of Water Temperature On Atlantic Salmon

- Water temperature is the only factor which has been studied to any great extent with swimming capabilities shown to be reduced at both low and high water temperatures (Thorstad *et al.,* 2008). Where water temperatures fall outside the normal tolerance range for salmon, obstacles may be more difficult to pass due to the increased physical exertion which may be required in order to do so (Thorstad *et al.,* 2008). This was shown to be the case for Atlantic salmon below 5-6°C, however it was noted that the degree of effect will be influenced by the specific location and how local populations have acclimatised to local environmental conditions (Thorstad *et al.,* 2008).
- Water temperature as a factor influencing migration was explored in an Environment Agency report (Solomon and Lightfoot, 2008). The report stated that survival in, and passage through, an estuary by returning adult salmon was influenced by temperature, particularly where other water parameters are critical. Temperatures of above 16°C were associated with reduced migration in estuaries and rivers with very little migration at temperatures of 20-23°C. Temperatures between 8-10°C were positively correlated with survival rate (Solomon and Lightfoot, 2008).
- A focused study on the Hampshire Avon showed a strong positive relationship between the proportion of fish passing promptly through the estuary and both water temperature and river flow (Solomon and Lightfoot, 2008). 37 fish tagged on days when the 09:00 river temperature was more than 19.8°C, none passed the tidal limit within 10 days. 6 fish which had been tagged when the 09:00 river temperature was a little below 19.8°C subsequently passed the tidal limit on days when the 09:00 river temperature was above 19.8°C, however at least 5 of these fish ascended past the tidal limit between 03:00 and 06:00 when the river water temperature was likely to be at its lowest (Solomon and Lightfoot, 2008). It was noted that half or more of the run could be lost during a hot, dry summer (Solomon and Lightfoot, 2008).

- A further study, bringing together data from fish movements into four rivers in South West England, identified that increased water temperatures are likely to represent a stress on migrating Atlantic salmon (Solomon and Sambrook, 2004). However, it was concluded that increased temperatures are not the primary cause of mortality for salmon delayed in the estuarine environment as temperatures in the studied estuaries did not approach the documented upper lethal limit (in the absence of other stressors) of 27.8°C (Sambrook and Solomon, 2004). It was determined that increased temperatures are likely to be a contributing factor with other adverse environmental factors. It was identified that increased temperatures often coincide with a deterioration in water quality, including lower levels of dissolved oxygen (Solomon and Sambrook, 2004).

1.4 Sea Trout Migration

- Sea trout are a migratory form of brown trout (*Salmo trutta*) which emigrate from freshwater and enter the marine environment at two points during their life history, at smelting and after spawning (kelts) (Johnsson and Jonsson, 2004; Bendall *et al.,* 2005; Whitlock *et al.,* 2017).
- The emigration of smolts down river and through the estuary is seen to be the critical period in their life history (Moore *et al.,* 1998; Bendall *et al.,* 2005). Kelts which return to their home river as repeat spawners are also an important component of sea trout stocks (L'Abee-Lund *et al.,* 1989) and can be considered as also being vulnerable to similar impacts as smolts during their post-spawning emigration within estuaries (Bendall *et al.,* 2005).
- Sea trout migrations can vary in duration and distance from periods of months within local coastal areas to years encompassing much greater distances within offshore areas (Sumner, 2015).
- Sea trout, unlike salmon species, can also spawn multiple times (Sumner, 2015; Whitlock *et al.,* 2017). This more variable life history resulting in the potential for increased inshore residence time means that sea trout are more likely to be vulnerable to inshore fishing practices than other species (Degerman *et al.,* 2012; Sumner, 2015).
- Studies have found that it is difficult to determine common patterns of marine migratory movement for adult sea trout (Malcolm *et al.,* 2010). Studies specific to the east and west coast of Scotland showed varying results with fish tagged on the east coast exhibiting wide ranging migrations (Malcolm *et al.,* 2010). It was concluded that the available data could not provide a reliable conclusion on the marine distribution of adult sea trout and this was identified as a significant gap in knowledge (Malcolm *et al.,* 2010).
- The main returning adult migration is seen to be between April and December in the UK (Sumner, 2015).
- A study of the contribution of sea trout to levels of offspring, compared to resident brown trout was carried out in Dorset during the spawning season in 2016 and 2017 (Goodwin *et al.,* 2016). Results using stable isotope analysis and microsatellite genotyping showed that despite the numerical dominance of resident brown trout adults, the maternal reproductive contribution to juvenile production was higher for anadromous females (76% compared to 2.5% for resident brown trout). Anadromous males were also seen to sire more offspring (63%) than resident males. Offspring from anadromous females were also noted to have an adaptive advantage and greater fitness in early ontogeny with a small number of anadromous females (6 fish) being the main drivers of reproduction in the river system studied (Goodwin *et al.,* 2016).
- Sea trout smolt, determined as being the most vulnerable life stage for the species, and kelts (post-spawning fish) are seen to move rapidly through estuaries using the ebb tide (Moore and Potter, 1994; Johnstone *et al.,* 1995; Moore *et al.,* 1998; Bendall *et al.,* 2005). This has been observed on the River Fowey (Bendall *et al.,* 2005), River Conwy (Moore *et al.,* 1998) and the River Avon (Moore and Potter, 1994).

- An acoustic tracking study on the River Fowey, Cornwall showed that fish which initiated migration through the estuary at the beginning of the ebb tide were able to move rapidly into coastal waters and often completed their passage through the estuary on a single tide Fish which entered the estuary later and failed to complete their passage within a single tide either maintained position or moved back upstream with the flood tide. Either way successful passage through the estuary was observed to be completed on the subsequent ebb tide (Bendall *et al.,* 2005).
- The average time a Sea trout spent within the River Fowey estuary was 6 hours and there was no document difference in behaviour between spring and neap tides (Bendall *et al.,* 2005)
- Studies show that the use of the ebb tide is energetically favourable for rapid movement through the estuary, helping to offset the impact on individuals who may have a reduced energy budget after spawning and greatly reduce time spent in the estuarine environment (Moore *et al.,* 1998; Bendall *et al.,* 2005).
- Evidence shows that in a lower part of an estuary, fish moved seaward against a flooding tide suggesting a switch from passive to active swimming, potentially as a result of salinity cues (Moore *et al.,* 1998; Bendall *et al.,* 2005). Upstream moving fish were also documented to actively swim against an ebbing tide with a mean detection time through the estuary of high water plus three hours in the River Fowey (Bendall *et al.,* 2005) and a maximum speed of 12.8km/day in the River Gudena, Denmark (Aarestrup and Jepsen, 1998). This behaviour suggests that sea trout do not need a long acclimatisation period in changing from freshwater to the marine environment and that the associated change in salinity and other parameters (within normal limits) does not introduce additional stressors (Moore *et al.,* 1998).
- Short passage times through the estuary also result in fish not being exposed for long periods of time to any adverse conditions such as poor water quality or elevated temperatures (Bendall *et al.,* 2005).
- Seaward behaviour of sea trout has been documented to be primarily nocturnal (Moore and Potter, 1994; Bendall *et al.,* 2005) but has also been seen to occur during the daytime (Moore *et al.,* 1998). There was no clear diurnal pattern of activity for upstream migrating fish although it appeared that migration mainly occurred during the daytime (Bendall *et al.,* 2005). Moore *et al.* (1998) also observed that fish orientated to remain in the main flow of the channel within the River Conwy estuary (North Wales) and when active swimming was initiated, swimming speeds were significantly in excess of the current flow.

1.5 Use Of Channels And Deeper Water Areas By Salmonids

- The geomorphological structure of the river environment encompassing location, size, slope, channel morphology and channel branching affects the time taken, difficulty and risk level associated with the salmon reaching their natal spawning grounds (Milner *et al.,* 2012).
- Based on hydro-morphological principles, it is likely that in lower reaches of rivers where channels are more stable, deeper and of lower energy, adult salmonids have an easier passage and are less dependent on the flow of water for movement, provided that there are no barriers to navigate past (Milner *et al.,* 2012).
- Data for Pacific salmon species indicates that actively migrating fish will more commonly used open-water migratory channels with the shoreline, wetland and shallow-water habitats preferred by fish which are estuarine-dependent (Roegner *et al.,* 2016).
- A study by Roegner *et al.* (2016) which investigated the migratory patterns of juvenile salmon from the Columbia River estuary, USA showed that smaller salmon (less than 1 year old, up to 140mm) preferred to use the shallower areas along the shoreline whereas fast-moving stocks of larger body size (1 year or older, greater than 140mm) used channels as migratory corridors.

- Low river flows were seen to delay the migration of Atlantic salmon in the River Fowey, Cornwall. Tagging showed that during this delay fish spent the majority of the time outside the estuary, however when fish did remain in the estuary during periods when background river flows were higher in the late spring and autumn, the fish held their position in deep water (Potter, 1988).
- A study of Atlantic salmon kelts in Canada showed that within the bay, fish migrated towards the deep channel where more temporally consistent current directions were identified (Hedger *et al.,* 2009).
- A study by Rogener *et al.* (2016) which looked at usage of different parts of the Columbia River basin by juvenile Pacific salmon species identified that shallow estuarine environments function as nursery or refuge habitats for small sized salmon fry (≤60mm).
- A review of studies on the usage of estuaries by adult Atlantic salmon indicated that the fish may use estuaries as holding areas but that they probably had little impact on the biological community as the estuary was used as a passage to freshwater rather than an area for feeding (Thorpe, 1994).

1.6 <u>Barriers to Salmonid Migration</u>

- Atlantic salmon are seen to be vulnerable to man-made obstructions (such as altered water discharges, dams and weirs) due to their life history traits (primarily a long distance between feeding and spawning areas) (Finstad *et al.,* 2005).
- In UK rivers, where they are no large migration barriers (such as weirs and dams) migration has been seen to take place mostly during the night, with movements starting at dusk and ending at dawn However, increased daytime activity has been noted during spate conditions and turbid water as well as instances where there are a number of obstacles within the river system (Thorstad *et al.,* 2008).
- Studies on nocturnal versus daytime migration patterns show mixed results, but there may be a conflict emerging between fishes' need for light in order to ascend past obstacles (Chanseau *et al.,* 1999) and a preference for darkness to aid avoidance of predators (Thorstad *et al.,* 2008). The different results appeared to depend on what the obstacle was, and the requirements associated with visual orientation in avoiding or ascending past it.
- The risk of a barrier to migration being created in harbours and estuaries is increased where a barrier occurs at a 'pinch point' or narrow area overlapping with the migration route. In these areas, the amount of water left for avoiding the barrier will be greatly reduced (per. Comm. Natural England and Environment Agency).
- Where impassable obstructions to upstream movement occur, this is where the likelihood of delayed or permanent stopping of migration is increased (Makinen *et al.,* 2000).
- Prolonged delays that prevent salmon from reaching their resting or spawning areas within the right time period will reduce reproductive success. Fish may be forced to spawn in unsuitable areas, or they may reach suitable spawning grounds too late (Thorstad *et al.,* 2008). Overripening of gonads as a result may have negative effects on egg viability, female spawning behaviour and spawning capacity. However, it is noted that as long as the salmon are able to reach spawning grounds in time before spawning (delayed versus permanent obstruction to migration) then the consequences for the population may be less severe although this has not been quantified (Thorstad *et al.,* 2008).
- Where fish which are not detected at spawning sites after disruption to migration, this does not mean that successful migration has been prevented but may mean that an extended period is spent in the lower reaches of the river while the fish re-orientates (Makinen *et al.,* 2000).
- Barriers to migration (such as dams, weirs and fishways) may not only delay upstream movement but may alter migratory patterns resulting in downstream movement, erratic movement or even result in some fish leaving the river to enter neighbouring rivers (Thorstad *et al.,* 2008). The biological significance of these behaviours is not widely known but may lead to a shift in the distribution of the spawning population (Thorstad *et al.,* 2008).

Running downstream as a result of disturbance and then having to re-ascend the river can cause stress which results in further delays (Thorstad *et al.,* 2008) and may also increase the chances of the salmon being re-caught by the same, or a different obstruction or by predators (Makinen *et al.,* 2000).

- The severity of the resulting impact from downstream movement is shown to be linked to the stage of upstream migration that the fish is in. Where fish are in the first stage of rapid upstream movement, the animal has not yet become established at its spawning site and therefore it is harder for them to re-orientate (Makinen *et al.,* 2000).
- Makinen *et al.* (2000) postulated that salmon which do not return upstream may have returned upstream into a different river, with particular relevance for fish in estuaries where multiple river systems exist.
- The occurrence of multiple barriers may have a cumulative effect on migration. It is noted that targeted salmon fisheries combined with weirs and other obstructions can increase blockages for salmon and reduce the amount of unobstructed water available for their upstream movement (Makinen *et al.,* 2000).
- Additional factors to man-made obstacles which may result in a cumulative effect on delaying migration are water discharge, water and air temperature, turbidity, atmospheric pressure, cloud cover and variations in concentrations of many dissolved ions (Thorstad *et al.,* 2008). The strength of influence of these factors may determine when other migratory obstacles can be passed, and therefore when and where upstream migration can occur (Okland *et al.,* 2001).

SECTION 1 CONTEXTUAL DISCUSSION POINTS

- The harbour and estuarine areas within the Southern IFCA District will fall within the first stage of migration for Atlantic salmon with steady periods of activity alternating with stationary periods. This is the stage of migration associated with the fastest migratory speeds and shortest residence time. Therefore, provided that salmonids have areas where they are not susceptible to interaction with nets the risk of interaction should be reduced compared to riverine areas.
- For sea trout, the emigration of smolts down river and through the estuary is seen to be the critical period in their lifecycle. The mesh size range currently used in the Southern IFCA District by ring nets and bottom set nets currently would have no impact on smolt. In addition, sea trout are seen to move rapidly through the estuarine environment reducing the time period during which an interaction could occur.
- The main migration period for Atlantic salmon varies between individual areas (April to December for River Itchen, February to December for River Avon). For sea trout the main migration period is between April and December in the UK. Local fishers have an understanding of these run times for their specific fishing area and often refrain from setting nets or modify fishing behaviours during this season in order to reduce the potential for interaction.
- It is noted that Atlantic salmon are seen to be more vulnerable to interactions during periods of increased water temperature and associated low water flows, where their residence time within estuaries increases. Sea trout are seen to be less vulnerable to changes in environmental conditions due to short passage times through the estuary. Net fishing does currently take place year-round in harbours and estuaries within the Southern IFCA District with gear deployment behaviours modified in certain areas around the salmonid run times. However, the level of reported and anecdotal interactions is very low, even at periods when temperatures would be increased. Temperature data from the River Avon and the River Itchen shows peak water temperatures between June and September. In 2019 IFCA Officers undertook observer trips across the range of net fishing methods currently used

over the period when the highest water temperatures would be expected, no interactions with salmonids were observed for any net fishing trip.

- Recognising the potential for this increased risk during the summer both due to the timing of the adult run and the increase in water temperatures, seasonal restrictions on netting practices which have the ability to provide more significant barriers (i.e. unattended, long soak time nets) would remove the combination of effects at a time when temperatures are more likely to be elevated to at or near critical limits for salmonids.
- Obstructions which are not impassable (i.e. do not cover the entirety of the water body available for migration) are likely to result in reduced stress and less severe disruptions to behaviour. Leaving areas where migratory passage is unimpeded will reduce the population impact for a particular location. It is unlikely, based on current fishing practice, that nets are commonly set in a manner so as to create a complete barrier to migration within harbours and estuaries. It is suggested that the main navigable channels are favoured by migratory salmonids, in certain areas within the District net fishing is already prohibited in these areas. It is recognised that, as the primary migration route, the management of net fishing within the main navigable channels of harbour and estuaries would be beneficial to reduce the risk to salmonid species.
- There is the potential for an increased risk to migrating salmonids through the use of nets within 'pinch point' areas such as the entrances to the Rivers Itchen and Test. These areas are narrower and therefore there is a higher risk of insufficient free water being available for fish to pass by the obstruction. Netting activity is currently known to take place within these narrower areas.
- There is an increased risk of creating barriers to migration through net methods which have long soak times as the barrier, created by the net is in place for a longer period of time. For the Southern IFCA District this would primarily be fixed nets which can be left for up to 12 hours before recovery.
- The current practices of using ring nets and bottom set nets greatly reduce the risk of a barrier to migration. Ring netting is a highly targeted method of fishing and the setting of the net in a circle results in a smaller area of water being covered. The use of bottom set nets within Southampton Water involves setting nets no higher than 3ft from the seabed. Atlantic salmon are known to orientate in inshore areas primarily in the towards the surface, particularly for upstream migrating adults, therefore the risk of this netting method creating a barrier is greatly reduced by leaving the surface of the water column free of obstruction.

SECTION 2: NETS AND SALMONID INTERACTION

Authors Note: The studies investigating the effects of mortality of salmon species almost exclusively look at fisheries where salmon are the target species. This is because there is currently a comparative lack of peer reviewed research looking at the impacts to salmon removed as bycatch (non-target species) from a net fishery. Where available, peer reviewed evidence and reports specific to non-targeted salmonid fisheries have been presented in Section 2.1.

It Is important to note that studies from targeted fisheries (Section 2.2) should not be considered to be directly comparable to the non-targeted net fishing activity taking place in the Southern IFCA District, rather the studies should be used to support wider understandings of salmonid behaviours when interacting with nets.

2.1 Non-Targeted Salmonid Fisheries

- Delayed mortality can occur as a result of a number of outcomes from interaction with fishing gear including direct injury caused by the gear, infection resulting from injuries caused and increased stress levels which can affect behavioural patterns (Makinen *et al.,* 2000; Vander Haegen *et al.,* 2004; Baker and Schindler, 2009 and Baker *et al.,* 2010).
- For fisheries where Atlantic salmon are not the target species, it is likely that delayed mortality will be more common than direct mortality as fish are removed as bycatch and returned to the sea, however post-release losses from delayed mortality and associated failure to reproduce often go unrecorded and are very difficult to quantify (Nguyen *et al.,* 2014).
- Fish mortality, generated directly or indirectly by fishing, but which is not included as part of catch statistics is referred to as 'non-catch fishing mortality' (Ritter *et al.,* 1979; Potter and Pawson, 1991). There are six defined types of 'non-catch fishing mortality':
  - **Predation mortality** – fish are caught in fishing gear and subsequently removed or damaged by predator activity to a point where they cannot be landed or are returned to the sea dead or severely injured (Ritter *et al.,* 1979; Potter and Pawson, 1991). This will largely depend on the fishing location and disposition of the nets (Potter and Pawson, 1991). Mammalian and avian predators are reported to be responsible for predation mortality of Pacific salmon in gill net fisheries (French and Dunn, 1973) and are likely to be responsible for predation mortality in all sea fisheries with Atlantic salmon (Ritter *et al.,* 1979).
  - **Escapement mortality** – fish that encounter fishing gear and are caught temporarily but escape and subsequently die from injuries, stress, disease or heightened risk of predation (Ritter *et al.,* 1979; Potter and Pawson, 1991). It is identified that the encounter with the net can be brief and mortality may occur may days or weeks later (Ritter *et al.,* 1979). Losses from escapement are hard to quantify however it is postulated that the percentage of fish escaping from a gill net is related to the range in size of the target species relative to the size selectivity of the gear being used (mesh size) (Ritter *et al.,* 1979; Potter and Pawson, 1991).
  - **Drop-out mortality** – fish are caught and killed by the fishing gear but drop out of the gear before it is hauled (Ritter *et al.,* 1979; Potter and Pawson, 1991). Drop out mortality is related to the construction of the fishing gear (Potter and Pawson, 1991) but will also be influenced by weather conditions, with greater drop-out rates seen during stronger winds and heavier seas (Ritter *et al.,* 1979).
  - **Haul-back or Fall out mortality** – fish are caught and killed by the fishing gear but are lost as the gear is hauled (Ritter *et al.,* 1979; Potter and Pawson, 1991). Fallout can occur either when the fish loses the buoyant support of the water (Ritter *et al.,* 1979) or as a result of the fisher's method of operation (Potter and Pawson, 1991). The

latter is identified as a strong influence on the level of this type of mortality (Potter and Pawson, 1991).
    - **Discard mortality** – fish which are caught in fishing gear but are discarded dead or die after being discarded from injuries or stress suffered during capture or handling (Ritter *et al.,* 1979; Potter and Pawson, 1991). This type of mortality is seen to be influenced by the mix of different species within the area where fishing is taking place (both target and non-target) and the length of time that a net is left to fish (Potter and Pawson, 1991). This is supported by Ritter *et al.* (1979) who identified that discard losses will increase in inclement weather which would prevent fishers from checking their nets for extended periods of time.
    - **Unreported catch (or 'other mortality')** – fish caught as bycatch, taken for personal consumption or illegally landed are often not recorded (Ritter *et al.,* 1979; Potter and Pawson, 1991).
- Different types of 'non-catch fishing mortality' will be relevant for different fishing activities. For gill net fisheries it is suggested that predation, escapement, drop-out and haul-back mortality are the most important (Ritter *et al.,* 1979).

2.1.1 The UK Bycatch Programme

The UK Bycatch Programme, run by the University of St Andrews, studied interactions between salmonids and net fishing methods. The programme recorded the number of salmon and sea trout caught by static and drift nets within ICES areas VIId and VIIe (encompassing areas of the Southern IFC District) outside of harbours and estuaries from 1998 onwards (to date unpublished).

- Results for area VIId: 780 inshore hauls, no salmon as bycatch, 1 sea trout as bycatch
- Results for area VIIe: 6010 inshore and offshore hauls, no salmon or sea trout bycatch

2.2 Targeted Salmonid Fisheries

Authors Note: Studies from peer reviewed literature to cover all aspects of potential impacts between net fishing and salmonids have not always been available specifically for Atlantic salmon. In this section, which deals with studies where salmonids are the target species, studies on other salmon species have been referenced. However, it is deemed that the similarity between the biology of the different salmon species is such that the overarching point on potential impacts can be related to Atlantic salmon, and therefore these references have been included as part of this literature review.

2.2.1 The SAMARCH Project

A study which forms part of the SAMARCH Project and is being run with the Game and Wildlife Conservation Trust (GWCT) research team. The study focused on sampling along the Cornish coast aiming to net for sea trout to undertake genetic analysis and compare locations of the fish to their natal rivers. The study used monofilament fixed gill nets, anchored and buoyed at each end, set for a soak time of 10-12 hours overnight. The netting was carried out by commercial fishers, under dispensation, in areas where gill netting for bass, mackerel, mullet, herring and other similar species is currently permitted. Preliminary data is available as follows, although the full results of the study have not yet been published.

- 5 Atlantic salmon were recorded caught in 3 nets, at 3 different locations (mesh: 4 inch/4.25 inch)
    - 1 x net set at depth of 25 feet (fish recorded as 'alive just', 690mm female)
    - 1 x net set at depth of 15 feet (two fish recorded as dead, 570mm and 730mm, both female)
    - 1 x net set at depth of 18 feet (two fish recorded as dead, 550mm and 625 mm, both male)

- Of the sea trout caught during the study, six were in the size range to be smolt (varying from 210-257mm)
    - 3.75-inch mesh: 4 smolt caught (dead)
    - 4.25-inch mesh: 1 smolt caught (dead)
    - 4.5-inch mesh: 1 smolt caught (dead)

2.2.2 Net marks and enmeshing

- Net marking is seen in numerous studies for net captured salmon (Vander Haegen *et al.,* 2004; Baker *et al.,* 2010; Veneranta *et al.,* 2018).
- Nearly all adult Chinook salmon captured in an 8-inch gill net were found to have net marks around the body, in front of the dorsal fin or around the gills (Vander Haegen *et al.,* 2004). The same study found that fish captured in a 5.5-inch mesh net had head marks around the snout rather than the main body. Where net marks occurred, they appeared to be severe with dislodged or missing scales and the underlying skin being red and abraded. It was predicted that a loss of protective slime would be associated with these types of injuries (Vander Haegen *et al.,* 2004). Where injuries were found on the snout rather than the main body however, scale loss was reduced and the overall injury to the fish was deemed to be less severe. Long-term mortality as a result of entanglement was concluded to be significantly lower in the 5.5-inch gill net when compared to a similar tangle net (Vander Haegen *et al.,* 2004).
- Net marks were also noted in 20-30% of fish caught in a targeted fishery for Sockeye salmon in Alaska (Baker *et al.,* 2010). It was noted that gill net marked fish showed a different length distribution to unmarked fish. For both sexes, gill net marked fish were smaller than fish which had escaped the fishery unmarked with 2-ocean males showing marking versus 3-ocean males and marking occurring exclusively in 2-ocean females. Large females were never entangled so were hypothesised to either have interacted with the net and escaped or not had any interaction.
- For sea trout, a study by Veneranta *et al.* (2018) identified the potential for direct mortality through the removal of fish by targeted sea trout fisheries, delayed pre-spawning mortality arising from injury and degraded reproductive potential (Veneranta *et al.,* 2018). The study involved fish being captured from gill nets (40mm mesh) and monitored in post-capture holding tanks for between 48 and 168 hours. The results of the study noted that larger Sea trout were often enmeshed by the teeth and bagged in the net while smaller individuals were enmeshed either primarily or secondarily around muscular tissue. 88% of the fish that became enmeshed around muscular tissue were found to have open wound injuries or chafes, for fish which were enmeshed by the teeth over 50% showed no visible damage (Veneranta *et al.,* 2018). Survival rates were seen to be high for larger fish enmeshed by the teeth (93%) with survival rates for those fish suffering injury dependent on the condition of the fish when disentangled. Fish observed to be in good condition showed a higher survival rate (84%), for those in a poorer condition, the survival rate was seen to decrease to 50% (Veneranta *et al.,* 2018). Survival was also seen to be linked to the length of time taken to disentangle a fish, with survival rate increasing with time taken to disentangle (55% for less than 30s to 71% for 61-126s). It was postulated that this was linked to the location of where the fish was enmeshed, with smaller fish able to be removed more quickly but being more likely to be enmeshed around muscular tissue compared to larger fish which took longer to removed but were most often enmeshed by the teeth and bagged in the net resulting in less severe or no instance of injury (Veneranta *et al.,* 2018). Despite the different degrees of injury observed, all fish that survived to the end of the observation period were observed to behave in a lively manner on release.

2.2.3 Physical damage, disease and infection following interaction with nets

- Baker and Schindler (2009) looked at impacts in relation to the severity of gill net injuries in tagged Sockeye salmon. 11-29% of salmon showed an injury from gill net interaction consisting of net marks, abrasions, contusions or scale loss. Longevity was reduced for moderate and severely injured fish, however fish with minor injuries lived longer than uninjured fish.
- Salmon captured in proximity to freshwater and their spawning season were observed to be more physiologically resistant to injuries and associated mortality than those fish at sea which are in their penultimate year prior to spawning (Ritter *et al.,* 1979). The fish were observed to have toughened skin which is thought to occur within five or six months of spawning in coastal areas whereas salmon which are feeding at sea and not destined to mature that year were physically much more delicate (Ritter *et al.,* 1979). The hardier fish entering coastal waters are thought to be less easily scaled.
- In a study by Baker and Schindler (2009) where 11-29% of Sockeye salmon showed an injury from gill net interaction, fungal infections associated with severity of injury were seen to be a major contributing factor. The percentage of fish suffering from an infection increased with severity of injury (6% minor, 76% moderate, 100% severe) and fish without a fungal infection lived 15 times longer that those that did, with a residence time which was twice as long.
- Scale loss was observed for enmeshed sea trout, with the degree to which this occurred being positively correlated with the degree to which the fish was enmeshed around muscular tissue (Veneranta *et al.,* 2018). Scale loss and the loss of the mucous layer is linked to an increased likelihood of the fish being susceptible to disease post-capture as is seen in studies with salmon species. However, despite differing degrees of scale loss, all surviving fish in the study by Veneranta *et al.* (2018) had recovered their mucous layer during the post-capture observation period.
- A further study looking specifically at scale and mucous loss in rainbow trout (*Salmo gairdnen*) demonstrated that a partial loss of scales or mucous did not result in increased mortality in a follow up period of 140 hours (Black and Tredwell, 1967).
- The main impacts from removal from nets are identified in the literature as follows:
  - Physical injury in the form of scale loss, skin abrasion and the loss of the protective slime layer
  - Increased risk of predation (Chopin and Arimoto, 1995)
  - Reduced resilience to disease and fungal infections (Chopin and Arimoto, 1995; Vander Haegen *et al.,* 2004; Nguyen *et al.,* 2014)
  - Reduced ability to grow or reproduce (Chopin and Arimoto, 1995; Baker and Schindler, 2009)
- The above factors are seen to be exacerbated by increased water temperatures (Brobbel *et al.,* 1996) for both upstream migrating salmon and salmon which have spawned and are returning to the sea. The level of air exposure in particular is seen to have more of a negative impact with increasing temperatures (Gale *et al.,* 2011).

2.2.4 Altered behaviour following interaction with nets

- In 2000, Makinen *et al.* studied the salmon fishery in the River Teno in Finland. Nineteen fish which had been caught by nets were tagged by hypodermic attachment of tags adjacent to the dorsal fin (no anaesthetic). They observed rapid downstream movement in all tagged fish at an average of 17.5km per day. Out of 16 salmon which were able to be analysed, all re-ascended the river with two maintaining a lower position before recommencing their ascent. Half ascended back into the river and past initial capture sites, the remainder were re-captured in the lower river. By the completion of the study 9 fish were recorded at suitable spawning sites with 8 still in unsuitable areas. Three of the salmon which suffered internal haemorrhaging and visceral damage from the net died shortly after tagging. The study concluded that, although gill nets can cause trauma, physical damage from net entanglement was minimal and short-term disruption did not affect ability to re-ascend the river.

- The notion that post-capture salmon were able to resume upstream migration is supported in a study by Siira *et al.* (2006). The study showed that for salmon captured, tagged, released and re-captured with commercial trap nets, more than 95% were recovered north of the tagging site or re-release location indicating that they had continued their spawning migration following capture and release. Maximum cumulative mortality for the total population after several capture and release events was reported as being less than 2% across two years of study.
- A study by Nguyen *et al.* (2014) where Sockeye salmon, gastrically implanted with coded radio transmitters, were exposed to multifilament gill net showed that although net injuries were observed, in the form of net marks and descaling and abrasions around the head/gills, downstream fallback on release from the gill net did not preclude subsequent upstream migration. It was observed that injury from the net slowed the initial, but not the subsequent migration rate of the Sockeye salmon. The results suggested that injury from the net was less disruptive to the immediate ionic balance of the salmon relative to other stressors.
- Baker and Schindler (2009) looked at impacts in relation to the severity of gill net injuries in tagged Sockeye salmon. 11-29% of salmon showed an injury from gill net interaction consisting of net marks, abrasions, contusions or scale loss. The study showed that 92% of fish with minor injuries entered their natal stream compared to 33% with moderate injury and 10% with severe injury. Fish with minor injuries were seen to hold off at the mouth of the river for twice as long as control fish and residence time decreased with increasing severity of injury (minor and moderate injury only, too few fish to determine effect of severe injuries). It was estimated that more than half of the fish that reached the natal spawning grounds after injury failed to reproduce.
- Berg *et al.* (1986) found that fish between 5 and 12kg which incurred damage from net entanglement behaved abnormally when compared to undamaged fish, choosing poor spawning sites and failing to cover fertilized eggs.
- Raby *et al.* (2012) looked at changes in reflex responses in Coho salmon where fish were biopsied and tagged after being exposed to stressors for up to an hour. The study looked at five separate reflex responses including body movement and orientation responses. It was found that salmon which failed to reach their natal sub-watershed showed a higher proportion of impaired reflexes than those that completed a successful migration. The change in reflex response was seen to positively correlate with stressor intensity although the author noted that the mechanistic link between reflex impairment, fish vitality and mortality is subject to speculation.
- The main impacts from removal from nets are identified in the literature as follows:
    - Physiological stress from exhaustion in fishing gear, handling, crowding, air exposure or prolonged exposure to warm temperatures:
        - Supressed immune function (Pickering, 1993; Nguyen *et al.,* 2014)
        - Reduced ability to osmoregulate (Pickering, 1993; Nguyen *et al.,* 2014)
        - Increased risk of predation (Pickering, 1993; Nguyen *et al.,* 2014)
        - Behaviour modifications i.e., instigation of downstream movement (Pickering, 1993; Nguyen *et al.,* 2014)
        - Delayed or prevention of spawning through impacts to upstream migration (Baker and Schindler, 2009)
- The above factors are seen to be exacerbated by increased water temperatures (Brobbel *et al.,* 1996) for both upstream migrating salmon and salmon which have spawned and are returning to the sea. The level of air exposure in particular is seen to have more of a negative impact with increasing temperatures (Gale *et al.,* 2011).

2.2.5 Physical damage combined with physiological stress following net interaction

- In the 1970s several studies were carried out looking at exposure of Sockeye salmon to gillnets under experimental conditions. These studies showed that a combination of physical damage (scale loss) combined with stress increased the percentage of post-capture mortality from 40 to 80% (Thompson and Hunter, 1973). Previous work, where salmon where exposed overnight to gill nets, showed that fish captured and released from gill nets were subject to higher levels of mortality than those who had scales purposefully removed (all scales anterior to the dorsal fin) suggesting that physical injuries that were visible were not the only damage sustained by fish in the nets, with physiological stress and neurophysical shock suggested as contributing factors (Thompson and Hunter, 1973). The author notes that there were sources of variation introduced by this experimental method which would not have affected fish in the sea including; a forced delay in migration by keeping fish in salt water when they should have been in freshwater and confinement in a holding area increasing the likelihood of injury and stress due to escape efforts.
- A study of sea trout in a targeted fishery observed exhaustion in fish independent of the degree and type of injury (Veneranta *et al.,* 2018). Attempts to escape from the net and associated stress were identified as a probable cause of longer-term effects on sea trout including vulnerability of fish to predators as well as reduced growth and overall condition of the individual (Veneranta *et al.,* 2018).

2.2.6 Mortality following interaction with nets

- Work carried out by Siira *et al.* (2006) looked at capture and release mortality without the additional stress caused by tagging, which is used in a number of experimental methods to monitor behaviour of many fish species including salmonids. Where tagging was used, the mortality level of fish was around 17%, although this was lower for Multi Sea Winter (MSW) fish. Net and release mortality (no tagging) was documented at 3% with maximum capture and release mortality (with all other influencing factors removed) being at an average of 11%.
- Gale *et al.* (2011) looked at the difference between simulated capture and simulated capture with additional air exposure on Sockeye salmon under a range of water temperatures. Salmon that were exposed to additional stressors above 'handling only' showed elevated lactate, sodium and chloride levels and decreased potassium levels as well as depressed ventilation and an inability to maintain equilibrium. However, the study detected no substantial relationship between short-term mortality and capture treatment at any temperature. Increased mortality was only observed at temperatures of 21°C or higher, a result which was expected as this is at or approaching the critical thermal limit for adult Sockeye salmon. It was noted that, as a result of river warming, an increasing number of adult Sockeye salmon were undertaking migrations at temperatures above their optimum range reducing their aerobic and cardiac scope for migration.
- Candy *et al.* (1996) used ultrasonic telemetry to monitor post-capture salmon and found that approx. 77% of Chinook salmon survived after capture and release from nets. Similarly, survival rates of spotted sea trout and lake trout in gill nets were shown to be 72% (Murphy *et al.,* 1995) and 68-77% (Gallinat *et al.,* 1997) at a period of 48 hours post capture. Experiments involving revival techniques showed that mortality rates could be reduced for Coho salmon released from commercial fishing gears, with a mortality of less than 3% for fish held in net pens for 24 hours (Farrell *et al.,* 2001). A second similar experiment corroborated this with mortality of Coho salmon only 2.3% for fish kept for a 24-hour observation period following release from gill nets (Farrell *et al.,* 2001a).
- However, a study by Gale *et al.* (2011) on Sockeye salmon under different capture conditions and water temperatures found that the use of 'recovery boxes' such as a Fraser box (holds the fish in flowing water to facilitate gill ventilation), to allow the fish to recover to 'normal' parameters before release, also had no discernible effect on migration success.

- In considering direct or indirect mortality there are several points which are raised in a number of studies which need to be considered.
  - The main consideration is the difference in effects on fish which are held in artificial circumstances compared to those in the wild. Fish held in artificial conditions are not subject to predation, changes in water temperature, waves, currents or other obstacles to migration which will have an additional impact for stressed or injured fish (Vander Haegen *et al.,* 2004; Siira *et al.,* 2006).
  - Many studies (Brobbel *et al.,* 1996; Vander Haegen *et al.,* 2004; Nguyen *et al.,* 2014; Veneranta *et al.,* 2018) concentrate on restricted time periods which will not allow for the influence of these external factors or variations in migratory behaviour, seen both seasonally and in individual fish (Jensen *et al.,* 2010), to be considered.
  - A consideration that migration has distinct sections i.e., rapid upstream migration in the first instance followed by a long residence period and then a short upstream migration prior to spawning (Makinen *et al.,* 2000). During the first phase of rapid upstream movement fish have not yet become established at spawning sites and therefore will require longer to re-orientate independent of the influence of stress or injury (Makinen *et al.,* 2000).
  - The size and age of the salmon also need to be considered as it is thought that Grilse (first sea winter fish) are more susceptible to physiological effects than Multi Sea Winter (MSW) fish (Jensen *et al.,* 2010).
  - Studies often lack reference groups or the ability to separate activity effects i.e., the effect of netting or catch and release angling from tagging effects (Jensen *et al.,* 2010). The process of tagging a fish introduces extra handling time, increased air exposure, sedation and transmitter attachment. In some cases, fish are not anaesthetised during this process increasing stress levels. The ability to confidently relate findings of telemetry studies to wild populations depends on the ability to minimise trauma to the fish and therefore lessen the extra influencing factor on behaviour or the extra stressor in addition to injury (Makinen *et al.,* 2000).

SECTION 3: NETS AND SALMONID INTERACTION: MITIGATIVE MEASURES

Authors Note: This Section discusses examples of mitigative measures that are thought to reduce the potential impact of net fishing on salmonids from impacts of being caught and from the impacts created by nets. A number of these measures are already employed by net fishers within the Southern IFCA District. As such this section is to be read in conjunction with the Conservation Assessment Package for the Net Fishing Byelaw and the Site-Specific Evidence Packages which have been developed as part of the Southern IFCA Netting Review. For ease, Contextual Discussion Points have been added by the Author where relevant in order to provide direct comparison with net fishing practice undertaken in the Southern IFCA District.

3.1 Good handling practice

- It is considered that the survival of a salmonid is influenced by the skill of the fisher in releasing the fish (Fraser *et al.,* 2002; Vander Haegen *et al.,* 2002; Vander Haegen *et al.,* 2004).
- Lower handling time and associated reduced air exposure are documented as being big contributors to reducing negative effects of gill net capture (Makinen *et al.,* 2000; Jensen *et al.,* 2010).
- Vander Haegen *et al.* (2002) detailed how fishers could be instructed on the proper handling of fish by avoiding touching the gill area or holding the fish by its caudal peduncle as it is removed from the net to avoid damaging tendons in the tail and also, during spawning, reduce the risk of rupturing reproductive sacs.
- Potter and Pawson (1991) also described the important of being able to remove a fish from the net in the direction in which it entered the net (the direction in which the scales lie) to minimise scale loss.
- Gale *et al.* (2011) highlighted the importance of reduced air exposure, particularly during higher water temperatures postulating that survival is increased due to reductions in equilibrium loss as well as reducing the magnitude of physiological impairments. The reduction in physical impairment will assist with more rapid resumption of upstream movement reducing the risk that spawning will be delayed or impaired.
- The handling process of fish post-capture was identified also as being important to promoting increased survival specifically for sea trout (Veneranta *et al.,* 2018). While increased handling time was positively correlated with survival it was still identified that correct handling practices should be adopted to reduce scale loss, air exposure and the risk of exacerbating injury.

3.2 Gear type and construction

- The gear construction will also influence the survivability of captured and released fish (Sirra *et al.,* 2006).
- It has been demonstrated that fish released from monofilament nets have a greater survival rate than those released from multifilament nets (Thompson and Hunter, 1971) with loss rates in some cases decreasing by half (French and Dunn, 1973).
- Potter and Pawson (1991) noted that monofilament nets can be more effective at fishing, primarily as they are less visible in the water, however the difference in catch as a result of this factor was seen to be greatest when nets are used in clear water which can be uncommon in estuaries and harbours subject to high degrees of other anthropogenic influences.
- A higher percentage of Sockeye salmon were able to disentangle from monofilament than multifilament net with a mesh range of 5 to 5 ¼ inches (Thompson and Hunter, 1973).
- Gill nets are seen to be more selective for their target species than other types of fishing i.e., trawl nets or seine nets as, for a particular mesh size, a large proportion of both target

and non-target species will be either too small or too large to become enmeshed (Anglesen, 1981; Potter and Pawson, 1991).

- The elasticity of modern netting material combined with the compressibility of the body of a fish will allow a fish with a girth larger than the circumference of the mesh to be more easily able to escape through the net. This is particularly true for salmon where experiments have shown that they can exert a considerable force on a mesh, generating a force equivalent to a load of several kg allowing the fish to force its way through the net (Potter and Pawson, 1991).
- Anglesen and Holm (1978) showed that out of 11 salmon squeezing through a gill net, 8 did so in less than 5 seconds and all escaped in under 25 seconds with no visible damage. For larger salmon, the study showed 70% disentangled within 10 seconds and 96% within 25 seconds, also showing no visible signs of damage. This is a short time period for the fish to struggle compared to estimated exhaustion times (from rod and line fisheries) which are estimated at 2 to 3 minutes (Makinen *et al.,* 2000).
- These factors result in gill nets having a low retention rate for non-target species, allowing a greater proportion of fish which encounter the gear to disentangle or escape (Baker and Schindler, 2009).
- In addition, fish which are larger still may not penetrate as far as the gills on first impact and may therefore drop out of the net with minimal impact. It has been demonstrated that large salmon are usually caught by their jaws and opercula and therefore are more likely to be able to disengage themselves (Makinen *et al.,* 2000).
- A study by Vander Haegen *et al.* (2014) showed that long-term mortality as a result of entanglement was concluded to be significantly lower in the 5.5-inch gill net when compared to a similar tangle net.

3.3 Deployment of fishing gear

- During periods of migration, salmonids are particularly vulnerable to gill nets set close to the shoreline and in or near estuaries to catch bass, mullet or flounder (Potter and Pawson, 1991).
- The effect of the net creating a barrier to migration can be reduced by restricting netting to certain times of year or by setting nets parallel to the shoreline or in deeper water where the headline remains well below the surface (Potter and Pawson, 1991).
- It has been reported that nets aiming to increase the likelihood of trapping migrating fish are usually set at right angles to the shore, whereas nets aimed at non-migrating species are usually fished parallel to the coast (Millner, 1985; Potter and Pawson, 1991).
- Where impassable obstructions to upstream movement are created the likelihood of delayed or permanent stopping of migration is increased (Makinen *et al.,* 2000).
- Use of fishing gear in combination with other barriers to migration (i.e., weirs, dams) may have a cumulative effect on migration by increasing blockages and reducing the amount of unobstructed water available for upstream movement (Makinen *et al.,* 2000).
- For sea trout, documented short passage times through estuaries result in fish not being exposed for long periods of time to any adverse conditions such as poor water quality or elevated temperatures (Bendall *et al.,* 2005). It is therefore thought that only where complete barriers to migration exist would fish be retained within estuarine areas for a period of time over which environmental factors would have a significant impact on health or behaviour.

3.4 Soak time

- Another important factor highlighted in the literature to reduce the risk of injury and mortality of salmonids as non-target species is reduced soak time/drift time for nets (Buchanan *et al.,* 2002; Vander Haegen *et al.,* 2004).

- Non-catch fishing mortality for coastal salmon gill net fisheries in the Pacific was noted to be low relative to the losses encountered in high-seas drift net fisheries (Ritter *et al.,* 1979). This is thought to be as a result of short duration of sets combined with frequent attendance of nets, generally calmer sea conditions (reducing drop-out and haul-back mortality) and the reduction in the presence of large predators (Ritter *et al.,* 1979).
- French and Dunn (1973) observed that, over a four-year period, mortality of maturing and immature Pacific salmon species from multifilament and monofilament nets increased with the length of time that the net was set (6.5% for 2.5 hours up to 40.5% for 10 hours). This was supported by Fraser *et al.* (2002) who compared soak times of 40 minutes to 140 minutes and found a significant reduction in mortality associated with shorter soak time ($P<0.001$). Estimates of mortality for 40 minutes were 2.5% versus 140 minutes at 60.4%. With shorter soak times, surviving fish were demonstrated to have recovered swimming ability to a level comparable to physiologically fit fish (1.44 body lengths per second).
- A study of sea trout in a targeted fishery observed exhaustion in fish independent of the degree and type of injury (Veneranta *et al.,* 2018). Attempts to escape from the net and associated stress were identified as a probable cause of longer-term effects on sea trout including vulnerability of fish to predators as well as reduced growth and overall condition of the individual (Veneranta *et al.,* 2018). As with salmon species, the degree to which a fish suffers stress and exhaustion from being entangled within a net is directly linked to the soak time of the particular net type.

SECTIONS 2 and 3 CONTEXTUAL DISCUSSION POINTS

- There are no main commercial net fisheries that target salmonids in the Southern IFCA District.
- From anecdotal reports by fishers and collation of evidence of interactions the level of interaction with salmonids is rare. Observation by Southern IFCA Officers during June-September 2019 across the range of net fishing methods currently used in the District showed no salmonid bycatch. In the context of the different types of delayed or ‘non-catch’ mortality, this rarity of interaction between salmonids and nets means that the risk of predation, escapement, drop-out, haul-back/fall out and discard mortality is greatly reduced (the first four of these being deemed to be most common for gill net fisheries). Unreported catch mortality from unwanted bycatch of salmonids will also be greatly reduced.
- Based on the number of reports and detected offences around salmonids within the commercial net fishing sector and anecdotal information from fishers, levels of unreported catch mortality where fish are being taken illegally is also likely to be low.
- In relation to the data provided by the SAMARCH Project (Section 2.2.1), it is important to note that although there is overlap between the mesh sizes used in the project and those used in the ring net fisheries across the Southern IFCA District (Sections D 2.3.2, D 2.5.2 of the Conservation Assessment Package for the Net Fishing Byelaw) there are differences in the deployment of the gear under the project when compared to ring net fishing in the District. The soak time of the nets used in the SAMARCH project is much greater than that used in the ring net fishery (10-12 hours versus 10 minutes) and in the SAMARCH Project, nets were weighted at each to create a sheet of net whereas ring nets are set in a circle on recognition of the presence of a target species. The method used in the SAMARCH Project is similar to some fixed netting practices across the District. However, while bottom set netting practices in Southampton Water have a similar soak time they are set so as to extend no more than 3ft from the seabed, leaving a large area above the net for fish to utilise without a barrier (See Section 1 Contextual Discussion Points).
- Sections 2 and 3 of this literature review reference the potential impacts to salmonids as a result of interaction with nets and the possible mitigative measures identified in the literature to reduce the risk of impact and ultimately, delayed mortality. Based on this, contextual

information is provided for the main commercial netting activities currently used in the Southern IFCA District.

- The main consideration for all net types is to reduce the creation of barriers to migration by nets (See Section 1 Contextual Discussion Points) and then, if entanglement does occur, reduce the resultant stress and likelihood of injury through correct practices.
- All the main commercial netting activities currently used in the Southern IFCA District (fixed netting with a specific type referred to as bottom set netting, drift netting, ring netting) are types of gill net. Gill nets are seen to be more selective for the target species than other types of fishing net (trawls, seine nets) for a particular mesh size. This low retention rate for non-target species, with reference particularly to salmonids, is supported by the low number of reports of interactions both from observer trips carried out by Southern IFCA over the full range of net types and anecdotal information from fishers in all areas.
- Considering mesh size specifically, smaller mesh sizes (5.5 inch relative to 8 inch) are demonstrated to result in Atlantic salmon being captured round the head and snout as opposed to the main body resulting in reduced scale loss, less severe injury and consequently, reduced long-term mortality. The lower end of the mesh range used in the reviewed study is comparable, and on the large side of, mesh ranges used in the District. Therefore, if interactions with salmonids do occur, fish are more likely to become enmeshed in an area where injuries are likely to be less severe or to a point where they can easily disentangle from the net (i.e. not penetrating as far as the gills), the latter of which also reduces the likelihood of stress and exhaustion impacts.
- An important factor highlighted in the literature to reduce the incidence of interactions, the degree to which a fish suffers stress and exhaustion, and the risk of delayed mortality should an interaction occur is soak time. A reduced soak/drift time will reduce the amount of time over which the net acts as a barrier to migration. If this is considered alongside optimal run times, then the level of impact to salmon from a net acting as a barrier would be greatly reduced. A reduced soak time also increases the likelihood that a fish will be able to be returned alive without suffering excess stress, and/or severe or fatal injury. The ring net fishery within the Southern IFCA District currently operates with very short soak times (approx. 10 minutes), shorter than any soak time referenced within the published literature. Soak times of 140 minutes and 40 minutes are documented to have mortality rates of 60.4% and 2.5% mortality respectively (Fraser *et al.,* 2002). Therefore, it can be inferred that the mortality rate for a 10-minute soak time would be lower than 2.5% all conditions being equal. It is recognised that environmental factors would play a role in changing the mortality rate, but the soak time used in the ring net fishery ensures the overall mortality rate is minimised.
- Net activities such as fixed nets and drift nets with long soak times would pose more of a risk to the level of interaction, the degree of stress and exhaustion a fish suffers, and likelihood of delayed mortality should an interaction occur. Consideration should be given to the location, seasonality and any other operational mitigative measures of these net types (i.e., pinch points, channels, timing of the adult run, setting depth) to reduce the likelihood of interaction given the increased risk of delayed mortality.
- The short soak time for ring net fishing in the District is coupled with the fact that ring nets are constantly attended, and therefore if a salmonid is observed interacting with a net, steps can be taken to release the fish in a timely manner thereby reducing the risk of stress and injury to the fish. For fixed and drift nets, nets are not always attended, therefore as with soak time, the risk level is increased for these net types. The mitigation would be the same as for soak time, reducing the potential for the interaction as the primary management driver.
- The potential for an interaction between salmonids and net fishing methods is also related to how targeted the fishing method is. Whilst it has been demonstrated that gill nets are more selective for the target species than other net types, there is still a difference in the ability of different net fishing methods used in the Southern IFCA District to target specific species. Ring nets in particular are the most targeted net fishing method currently used.

The fishers who engage in ring netting are highly experienced at setting nets only on recognition of the presence of target species (primarily grey mullet species). For other netting types, fishers are equally experienced in setting of nets to maximise the retention of target species. However, fixed and drift nets are set for longer periods of time and therefore are not as specific in terms of being set following identification of the target species in a particular area. There is therefore the potential for an increased risk of interaction with non-target species for these net types. The degree of risk will also be dependent on other variables such as location, time of year and orientation in the water column.

- Fishers have indicated that they observe good handling practice when dealing with the removal from a net and subsequent release of non-target species. Based on the documented and anecdotal low interaction rate with salmonids this good handling practice is more likely to be used on non-salmonid species, however the basic principles employed of reducing air exposure, removing the fish in the direction it entered the net and avoiding over handling (to reduce scale loss and body damage) are all measures which are highlighted in the literature as being important for minimising post-capture stress and delayed mortality in salmonids.
- Further details on the current net fishing methods used in each proposed management area and the use of these areas by salmonids is provided in the Conservation Assessment Package for the Net Fishing Byelaw and the Site-Specific Evidence Packages, developed as part of the Southern IFCA Netting Review.

SECTION 4: ESSENTIAL FISH HABITATS FOR NON-SALMONIDS

The management of nursery, feeding and refuge areas to benefit fish is common practice in international fisheries management. Such areas are commonly termed 'Essential Fish Habitat (EFH)' in fisheries management.

An EFH is a habitat identified as crucial to the ecological and biological requirements for the critical life cycle of exploited fish species, which may require special protection to improve stock status and long-term sustainability (STECF, 2006). In particular, EFH refers to the waters and substrate necessary for fish to spawn, breed or feed (Rosenberg *et al.,* 2000). Examples of EFH include (adapted from M. Bergmann *et al.,* 2004):

- Nursery grounds: areas where the highest concentrations of juvenile fish are found.
- Feeding grounds/foraging grounds: areas, where increased feeding activity takes place; and
- Refuge habitat: areas where fish congregate to rest or seek refuge from predators.

4.1 Estuaries & harbours as spawning and nursery areas

- Marine fish visit coastal and estuarine waters to spawn or have pelagic larvae which migrate inshore to utilise these habitats as juvenile nursery areas (Pihl *et al.,* 2002).
- Coastal habitats defined as 'Highly productive estuaries and bays…and home to a number of invertebrates' are of high importance for 44% of all ICES species. These coastal stocks alone contributed 77% of the landings of ICES advice-species highlighting the importance of coastal habitats to fishery yield and population maintenance. The majority of these habitats are important as nursery grounds, feeding areas and for spawning (Seitz *et al.,* 2014).
- Marine fish use estuaries in a number of ways and can be categorised as either marine estuarine opportunists, those which enter estuaries in large numbers at some stage in the lifecycle (typically juvenile), a marine estuary dependant, those that depend upon these systems for survival at a critical stage in their lifecycle or, a estuarine migrant, those which spawn in estuaries but may be flushed out to sea as larvae and later return at some stage to the estuary (Potter *et al.,* 2013).

4.1.1 Spawning

- Sandsmelt (*Atherina presbyter*) are found as both larvae and juveniles in estuaries suggesting these areas are important for this species as both spawning and nursery areas, whilst common sole (*Solea solea)* is present in estuaries only as juveniles. Their larvae are found in more coastal areas showing that the habitats are used as nursery areas (Guerreiro *et al.,* 2021).
- Thin-lipped grey mullet are found in shallow waters and estuaries at a range of size classes. They spawn in estuarine habitats in Europe from June to August (Glamuzina *et al.,* 2007).
- Golden grey mullet are an euryhaline and eurythermal species tolerant to large salinity and temperature ranges. They are found to spawn in estuarine waters around the world, between August and November in the Istanbul Golden Horn Area (Kesiktaş *et al.,* 2020).
- Atlantic herring migrate to shallow coastal areas to spawn in seagrass and saltmarsh onto which they attach their eggs (Seitz *et al.,* 2014 & von Nordheim, 2019).
- Coastal habitats are also important as nursery areas for invertebrates. Whelks, the common cockle and blue mussel utilise these habitats for spawning (Seitz *et al.,* 2014).

4.1.2 Nursery

- Once European bass eggs have hatched the pelagic larvae slowly move inshore over a 2–3-month period (Haffray et al., 2000; Pawson and Pickett, 1987; Dando & Demir, 1985). After reaching 15 mm in length the larvae actively swim into estuaries, shallow bays and brackish water and remain in these nursery habitats for two years (Pawson, 1995). In their second- or third-year juveniles migrate to overwintering grounds in deeper water, returning each summer to large estuaries until 5 to 6 years of age (Pawson, 1995 & Hyder *et al.,* 2018). Sixty-five percent of tagged bass all less than 36cm in length were recaptured in fisheries local to the tagging sites, highlighting that juvenile bass show site fidelity beyond their first two years (Pickett *et al.,* 2004).

- Young of the year flatfish, such as common sole (*Solea solea),* plaice *(Pleuronectes platessa)* and European flounder *(Platichthys flesus)* show high site fidelity for their intertidal and subtidal soft bottom essential nursery habitats of (Le Pape & Cognez, 2016).
- Intertidal soft bottoms provide nursery and feeding habitat for dab, flounder and plaice, whilst kelp habitats provide nursery and feeding habitat for cod (Seitz *et al.,* 2014).
- There is little doubt that seagrass meadows, mangrove forests, salt marshes and reed beds act as important nursery areas and food sources for fishes in estuaries (Whitfield, 2017).
- The availability of essential nursery areas for fish early life stages can limit the abundance of later adult stages of predatory fish. This combined with low to moderate adult fishing mortality limits the population size in each area (Sundbald *et al.,* 2014).
- Coastal habitats are also important as spawning areas for invertebrates. The European lobster and edible crab utilise intertidal and subtidal soft bottoms as nursery and feeding areas for juveniles (Seitz *et al.,* 2014).

4.2 Essential fish habitats for feeding

Intertidal and subtidal mudflats and mixed sediments support a rich density of invertebrates, including bivalves, polychaete worms and amphipod crustaceans, providing prey species for coastal fish communities. Larger fish species may also be attracted to these areas where denser populations of fish are found both on the benthos and in the water column.

4.2.1 Intertidal and subtidal mudflats

- The total density of fishes in European estuaries is correlated to the proportion of intertidal mudflats. Those estuaries with 80-100% intertidal mudflats had the highest densities of fishes at 61 individuals 100mm^2 (Nicolas *et al.,* 2010). Estuaries support the majority of marine migrant, marine straggler, and estuarine species particularly at their juvenile stage.
- Prey availability in shallow mudflats is a strong predictor of community level juvenile fish nursery areas (flatfishes and round fishes), suggesting that high prey availability within these habitats is one of the drivers for their importance as nursery grounds (Tableau *et al.,* 2016).
- The presence of copepods (*Corophium volutator)* and marine worms (oligochaetes and polychaetes) on/in mudflats for juvenile flounder diet is key in estuarine habitats (Summers, 1980).
- Juvenile common sole (*Solea solea*) occur in high densities in shallow areas, with fine sediment where they rely upon the presence of polychaetes, molluscs and crustaceans as their main source of diet (Vinagre, 2007).
- Common sole appears to receive significant energetic benefits (indicated by mass and total length data) from estuarine feeding, likely due to the particularly high productivity of their polychaete prey within estuaries (Leakey *et al.,* 2008).
- Intertidal and subtidal soft bottoms are particularly important as nursery habitats, as well as showing some use for spawning and feeding for many commercially important fish species. Species including dab, whiting, red mullet, flounder, plaice, pollack, turbot, brill, and sole use these habitats as nursery grounds for juvenile fish (Seitz *et al.,* 2014).

4.2.2 Saltmarsh

- Despite salt marshes flooding only in high tide, fish feed actively during this period in these habitats (Whitfield, 2017).

- European seabass return to salt marshes and marsh creeks each flood tide to feed upon mysid shrimps and amphipods in estuarine waters (Laffaille *et al.,* 2001).
- In Southeast England 0-group bass (30-59mm) fed predominantly on *Carcinus maenas, Nereis spp*. and amphipods in established saltmarshes (Fonseca *et al.,* 2011).
- Foraging profitability is significantly enhanced by feeding in vegetated creeks (Rozas & Odum, 1988).

4.2.3 Water column

- Highest species richness of fishes is found in estuaries at the polyhaline (18 to 30) salinity and those estuaries with large entrance widths (Nicolas *et al.,* 2010).
- Shallow open waters less than 30m in depth provide essential feeding, nursery, or spawning areas for mackerel, sole and sprat (Seitz *et al.,* 2014).
- Estuaries receive large supplies of inorganic carbon and nutrients from land runoff, which supports high rates of primary and secondary production (Hopkinson et al., 2005 & Beck *et al.,* 2001). There is a positive bottom-up association between primary production and subsequent trophic levels such as zooplankton (Capuzzo *et al.,* 2017).
- Herring, sprat, and sand eel feed upon zooplankton found in the water column. Herring are found in areas where zooplankton densities are highest (Garcia *et al.,* 2012).
- 0-group bass (15-39mm) predominantly consume copepods in Southeast England estuaries (Fonseca *et al.,* 2011).
- Large fish such as European sea bass are attracted to feed in estuarine waters due to the range of prey species available, such as those which inhabit the benthos for instance copepods, to free swimming small fish such as gobies (Pasquaud *et al.,* 2010).
- Adult seabass tagged around the coasts of England and Wales are recaptured close to their respective tagging locations indicating site fidelity for feeding areas (Pawson *et al.,* 2008).
- Estuaries support both small and large piscivorous fish, with the juvenile stages of large piscivorous fish more likely to be found due to their size and manoeuvrability within complex estuarine habitats (Sheaves, 2001)

4.3 Essential fish habitats for protection

4.3.1Seagrass

- Seagrass beds have a complex 3D structure which provides juvenile and small fish protection from predators (Heck *et al.,* 1997)
- In the field, experiments showed that crabs were taken as prey in significantly fewer numbers in turtle grass and drift algae than on bare sand (Heck & Thoman 1981).
- Laboratory and field experiments within eelgrass (*Zostera marina)* and artificial seagrass found that small fish prey which remain within vegetative cover enhanced their chances of survival. However, data also suggests that predators utilise eelgrass beds as foraging grounds. The research shows that seagrass habitats are important for fish at multiple trophic levels (Lascara, 1981).
- Overall, fish abundance, biomass, species richness, dominance, life history and diversity increased significantly along the gradient of increasing eelgrass habitat complexity (Deegan, 2002).

4.3.2 Saltmarsh

- The lower estuary and saltmarsh areas are important feeding and nursery areas for a range of fish groups including Mugilidae (mullets), Sparidae (breams), Soleidae and Moronidae (temperate basses) (Sa *et al.,* 2006).
- Relative predation pressure is significantly less in areas of marsh creeks than those which are unvegetated. Tethering experiments of mummichogs fish in vegetated and unvegetated areas showed a 10-30% higher risk of predation (Rozas & Odum, 1988).

- Numerical experiments found that restoration of saltmarsh and seagrass habitats would yield an 24% increase in post settlement survival of Red drum (*Sciaenops ocellatus*) and would result in a 2% increase in population growth rate, enough to stem a long-term population decline. The research highlights the importance of essential fish habitat for exploited fish populations to withstand fishing pressure and to increase the viability of a fishery (Levin & Stunz, 2005).

4.4 Net fishing impacts

4.4.1 Bycatch in net fisheries

- Gill nets and trawls used within shallow coastal areas capture juvenile fishes at probabilities as high as 0.95 which is likely to affect the recruitment of bycatch species (Amezucua *et al.,* 2009).
- Sampling of gillnet fisheries across six estuaries and three fishing seasons in South-eastern Australia found that 6.2% by number and 3.3% by weight of catches were discarded. Discarding was greatest in smaller mesh sizes and during winter when nets are set and left-over night (Gray *et al.,* 2005).
- Juvenile fishes of both commercially targeted and non-target species are caught in net fisheries within near shore ecosystems, with discards accounting for 19% of total catches by weight (Blaber, 2000 & Gray, 2002).
- Set gillnets used in small scale fisheries had the highest overall impact on non-target species, with discard rates as high as 34.3% - higher than most industrial fisheries (Shester & Micheli 2011).

4.4.2 Mortality

- Fish using essential fish habitats can become non-target catch of net fisheries within estuaries and rivers. In the New River estuary North Carolina, survival of discarded fishes such as southern flounder in a commercial gill net fishery can be as low as 0.22-0.3 during summer, and as high as 0.87 in autumn and spring. The overall survival rate for sublegal fish was 0.5. A positive effect was found between body size and post release survival (Smith & Scharf, 2011).
- Riverine/estuarine gillnet fisheries are a major source of mortality for species, such as the southern sturgeon, in their essential habitat at their spawning stage of their life cycle with immediate capture mortality at 16% (Collins *et al.,* 2000).
- Bycatch within inshore net fisheries has been found to be 20% in Queensland sea mullet, whiting and mackerel fisheries. Field trials found that for one species post netting mortality was zero, whilst the most vulnerable species showed a post netting mortality of 67% (Halliday *et al.,* 2001).
- Eighteen percent of juvenile fishes of both commercially targeted and non-target species show mortality when caught in net fisheries within near shore ecosystems (Blaber, 2000 & Gray, 2002).
- Monitored gillnet fishing operations of inshore net-fisheries in Western Cape South Africa, showed that 4.2% of the total catch was bycatch, mostly consisting of immature, undersized fish that were often injured and did not survive (Hutchings & Lamberth, 2002).

4.4.3 Spawning behaviour

- Fishing for cod in spawning aggregations led to more complex impacts than fish removal. The aggregation behaviour was disrupted with increased vertical movement and dispersal away from the area after which fish did not return within the 9-day study period (Dean *et al.,* 2012).

SECTION 4 CONTEXTUAL DISCUSSION POINTS

- Different habitats are identified in the literature as having beneficial use by fish species for spawning, for feed, as nursery areas and for protection. The main habitats referenced in the literature are saltmarsh, seagrass, intertidal and subtidal mudflats and the water column, all of which are commonly found in different harbours and estuaries across the Southern IFCA District.

- The species mentioned specifically in the literature as relying on these habitats are also all commonly found within the Southern IFCA District.
- Saltmarsh habitats are found in Langstone Harbour, Portsmouth Harbour, Southampton Water, Kings Quay, The River Medina, Keyhaven, Lymington, Christchurch Harbour, Poole Harbour and The Fleet.
  - Saltmarsh habitat is utilised for net fishing activity of all types (ring net, fixed net, drift net). Where net fishing does occur in saltmarsh areas it is particularly focused on the creeks created between the saltmarsh. These are areas in which fish are more likely to congregate for protection.
- Seagrass habitats are found in Langstone Harbour, Portsmouth Harbour, the mouth of the River Meon, Kings Quay and Poole Harbour
  - Seagrass habitat is utilised less for net fishing activity. Where seagrass beds occur within the District, these are often smaller in relation to the size of the overall area resulting in a wider area for fishers to use outside of the seagrass habitat. Areas outside seagrass are often preferred for net fishing due to the difficulty in setting and recovering the net in this type of habitat.
- Either intertidal, subtidal or both types of mudflat habitat are found in all harbours and estuaries being reviewed under the Southern IFCA Netting Review.
  - Where net fishing occurs in harbours and estuaries within the Southern IFCA District, almost all of the activity will occur over mudflat habitat. However, based on contextual evidence discussed earlier (See Sections 2 and 3 Contextual Discussion Points), net fishing activity does not result in entire areas being closed off or covered by a net, therefore an area for feeding and as a nursery area will always be available at any given time for species to utilise.
- Water column habitat is found in all harbours and estuaries being reviewed under the Southern IFCA Netting Review.
  - As above, where net fishing occurs in harbours and estuaries within the Southern IFCA District, all of the activity will occur within the water column. The same argument as for mudflat habitats, of net fishing not utilising the entirety of a single area, is made in relation to impacts to the water column.
- Summaries of the ecological value of each specific management area as an Essential Fish Habitat are given in the Site-Specific Evidence Packages.
- Contextualising the information presented in this literature review with knowledge about harbours and estuaries in the Southern IFCA District indicates that certain net fishing operations have the potential to impact areas identified as Essential Fish Habitats.
- Bycatch of juvenile fish and non-target species is highlighted in the literature as being high for gill net fisheries in near shore ecosystems and shallow coastal areas. The literature does show that set gillnets and those left overnight caused the greatest level of discards which relates to the practice of fixed netting within the Southern IFCA District. It is also important to consider that in areas where there is limited available area for fish to avoid a net, such as saltmarsh creeks, all types of netting may have an impact whether it be for juvenile fish or adult fish using the area for spawning or feeding.
- All net types used in the Southern IFCA District have mesh size ranges based on the target species. Whilst the literature review highlights that mesh species based on target species may result in the bycatch of non-target adult of juvenile species, there is no evidence to quantify the level of bycatch of juvenile species by netting methods used specifically in the Southern IFCA District. It is therefore operational behaviours such as geographical location

in which nets are set, seasonality and soak time which will provide the best mitigation against increasing the risk of impacts to essential fish habitats.

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