Annex 10.2

Assessment of Potential Impacts of Able Marine Energy Park on Sea and River Lamprey in the Humber Estuary

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Assessment of potential impacts of Able Marine Energy Park (AMEP) on sea and river lamprey in the Humber Estuary

Report to ABLE UK Ltd

Institute of Estuarine and Coastal Studies
University of Hull

8th September 2011

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For and on behalf of the Institute of Estuarine and Coastal Studies

Approved by: Nick Cutts
Signed:
Position: Deputy Director
Date: 8th September 2011

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1. INTRODUCTION

1 The Institute of Estuarine and Coastal Studies (IECS, University of Hull) was commissioned by Able UK Ltd (Able) to undertake an Environmental Impact Assessment (EIA) of the effects of the proposed Able Marine Energy Park (AMEP) on river and sea lamprey in the Humber estuary.

2 The EIA process seeks to identify those impacts associated with the development through all phases of its evolution. These are based on knowledge of the existing environment (baseline conditions), the definition of the project proposed and the response of the environment to the potential changes. Where possible, mitigation is built into the project design to reduce impacts "at source", and where this is not possible a range of mitigation measures may be applied to reduce any residual impacts which might arise, often with a monitoring condition attached.

3 The EIA process described in this report provides a description of the potential impacts of construction and operation upon the river and sea lamprey within the proposed development area, with particular regard to the marine development of the AMEP site.

4 The AMEP has been designed to provide, in the first instance, a manufacturing base for offshore wind turbines (OWTs), thus contributing towards a secure and balanced energy mix for the UK. The AMEP structure will include quays to receive and export raw materials and products, as well as facilities that will be necessary to assemble the OWT components in preparation for loading onto installation vessels for direct transport to offshore wind farms.

5 The AMEP is situated in an area known as Killingholme Marshes on the southern bank of the Humber Estuary, approximately 2km from the village of North Killingholme to the west, and 3.3km from Immingham to the south. This site lies between the Humber Sea Terminal (HST) and ABP Port of Immingham. The AMEP will comprise development areas on terrestrial land, and on existing intertidal and subtidal areas. These latter areas will be located within the boundaries of the Humber Estuary and will extend from the existing tidal defences to the edge of the existing dredged channel that provides access into the HST.

6 The marine development at the AMEP site will include a 1200m quay consisting of a suspended deck over 250m and over the remainder a front wall that comprises a combination of large diameter tubular steel piles alternating with steel sheet piles. Capital dredging operations will be required to remove the compressible silt present over part of the footprint of the proposed new quay by a trailing suction hopper dredger before placing any fill material as well as to enable vessel access to the operational quay and allow berthing alongside its length over a commercially viable tidal range. The large diameter tubular piles that will form part of the quay wall will be vibrated through any soft superficial deposits that are present and will then be driven to their design depth using hydraulically operated piling hammers. The sheet piles will also be driven by a vibrating ram until they reach their design level (although they might need also to be driven if they refuse before attaining the desired level). The existing intertidal area between the existing flood defence and the new quay will be backfilled with sea dredged material by rainbowing from a dredger that would be berthed sea side of the quay wall. A minimum 2 year construction programme has been anticipated for the marine works. Once the development is complete, maintenance dredging will be required from time to time.

7 On completion, the quay will be used for the export of marine energy components and for the import of materials and components that are procured from overseas or from other coastal locations within the UK. The quay will operate 24 hours a day and the operational

areas of the quay will extend to 50m of the quay edge. The development area will be drained by a network of land drains that will discharge into the Humber Estuary (after having passed through oil interceptors at locations where a high risk of oil spillage exists).

8 Given that the new quay will replace an existing flood defence wall and will protect the immediate hinterland and adjacent properties from flooding, it will be maintained to ensure that it continues to provide appropriate flood protection, hence no decommissioning is anticipated.

9 The construction and operation of the marine development at the AMEP site will inevitably have some impact upon the physical properties of the seabed and the quality of the overlying water with consequent impacts upon the benthic communities and fish present and, ultimately on their predators (sea mammals and birds). This document provides specific information on the impacts of the proposed development on sea and river lamprey.

10 *Lampetra fluviatilis* (river lamprey) and *Petromyzon marinus* (sea lamprey) are anadromous fish species using the Humber Estuary as pathway of migration between the adult marine environment and the riverine spawning grounds. These two species are also included in Annex II of the EC Habitats Directive and are qualifying feature of the Humber Estuary Special Area of Conservation (SAC) (English Nature 2003). The River Derwent, a tributary within the Humber catchment, has also been designated as a SAC. SAC sites are designated and conserved in order to maintain or restore the habitats listed in Annex I and the species listed in Annex II of the Directive to favourable conservation status. In addition to river and sea lamprey, Annex II includes allis shad (*Alosa alosa*), twaite shad (*Alosa fallax*), brook lamprey (*Lampetra planeri*) and Atlantic salmon (*Salmo salar*). To ensure favourable conservation status populations of these species must be maintained or increased over time. In some parts of the UK the identification of suitable SAC sites for river lamprey has been hampered by the absence of comparative population data.

11 A thorough review of the scientific and grey literature available has been carried out to characterise the general ecology of the two species and their status in the Humber Estuary (Section 2) as well as their potential sensitivity to the pressures which will arise from the construction and operational stages of the AMEP site (Section 3), in order to inform the EIA for the proposed development and also the Habitats Regulations Assessment report.

2. SEA AND RIVER LAMPREY BASELINE ECOLOGY

12 This section informs on the general ecology of sea and river lamprey and on their occurrence and status in the Humber Estuary.

2.1. General ecology

13 Lampreys (Family: Petromyzontidae) belong to a group of primitive vertebrates, the Agnatha or 'jawless fish' (Maitland and Campbell 1992). Lampreys are characterised by their eel-like bodies, round sucker-like mouths, very poorly developed fins, scaleless skin and by a row of seven breathing holes instead of gills (Phillips and Rix 1985). They have no bones, all the skeletal structures being made of strong, flexible cartilage. A round sucker-like disc surrounds the mouth, within which, in the adults, are strong rasping teeth, their size, shape, number and position varying among species.

14 The majority of lamprey species are anadromous fish which spawn in freshwater but complete part of their life cycle in the sea, where they adopt a parasitic lifestile, feeding on the body tissues and blood of other fish species.

15 The sea lamprey *Petromyzon marinus* are the largest of all the lamprey species, with adults ranging from 60 to 90cm, weighting approximately 2-2.5kg, although they may measure up to 120cm (Kelly and King 2001; English Nature 2003). The species occurs in estuaries and easily accessible rivers over much of the Atlantic coastal area of western and northern Europe from northern Norway to the western Mediterranean and eastern North America (English Nature 2003). In the UK, the species appears to reach its northern limit of distribution in Scotland and does not occur north of the Great Glen (English Nature 2003). Within UK rivers the sea lamprey is reasonably widespread, in some places it is still common, but it has declined in parts of its range and has become extinct in a number of rivers (English Nature 2003).

16 The river lamprey *Lampetra fluviatilis* is smaller than the sea lamprey, the adults being 20-50cm long, although they rarely exceed 45cm (Kelly and King 2001; English Nature 2003). The species occurs only in western Europe, where it has a wide distribution from southern Norway to the western Mediterranean. Within the UK, the river lamprey has been recorded from numerous inland rivers and estuaries along the north and east coasts, south and west coasts, Wales and Scotland (English Nature 2003). There are a few land-locked populations, including one in Scotland which is seen as having special European importance (English Nature 2003).

2.1.1. LIFE CYCLE

17 The general life cycle of sea and river lamprey (and of the majority of lamprey species) is summarised in Figure 1 (Kelly and King 2001).

18 Adults migrate upstream into rivers to reach the spawning areas, where they spawn in pairs or groups, laying eggs in crude nests or shallow depressions in alluvial material. The river upstream migration takes place almost exclusively at night, with adults being sedentary during the daytime, resting under rocks and riverbanks, and its timing varies with latitude, temperature and discharge (Hardisty and Potter 1971; Potter 1980b; Hardisty 2006). Periods of increased discharge from the river into the estuary have been reported as a major factor in the initiation of upstream migration by river lamprey (Abou-Seedo and Potter 1979), although migratory activity might be reduced at the highest flows (Masters *et al.* 2006). Across Europe the timing of the upstream migration of river lamprey can vary greatly from late summer to spring although in the southern part of the UK, river lamprey generally migrate in autumn / early winter (October - February), with adults spending the winter in freshwater before spawning (Pickering 1993; Lucas 1998; English Nature 2003;

Jang *et al.* 2005). In turn the upstream migration of the sea lamprey generally occurs between spring and early summer, one or two months before spawning (Hardisty and Potter 1971), although migrating adult sea lamprey have also been recorded in estuaries during autumn (October) (English Nature 2003). During the upstream spawning migration, no feeding activity takes place, leading to a period of natural starvation (Kelly and King 2001). Being poor swimmers, migrating lampreys generally move in shallow waters, along the edges of the main stream, particularly when the river current is strong (Kelly and King 2001). When faced by barriers along the river, they exhibit sustained exploratory movements, passing backwards and forwards along the surface in search of a passage (Hardisty and Potter 1971).

19 According to Hardisty and Potter (1971), water temperature is the decisive factor in determining the onset of spawning. In British rivers, the spawning season for river lamprey generally extends from March to April and begins when water temperatures reach 10-11°C, whereas sea lamprey breed in early summer months (May to July) at a water temperature of at least 15°C (Wheeler 1969; Kelly and King 2001; English Nature 2003). The lamprey spawning habitat requires a gravel bed with swift-running water and nearby backwaters with muddy bottoms for the larvae (Wheeler 1969). The eggs are laid in a nest excavated by both males and females. Lampreys are usually semelparous (i.e. they are characterised by a single reproductive episode before death) and adults die shortly after a single spawning, following endocrine-mediated changes in physiology (Larsen 1980), although some sea lamprey may migrate back out to sea and respawn during subsequent years (English Nature 2003).

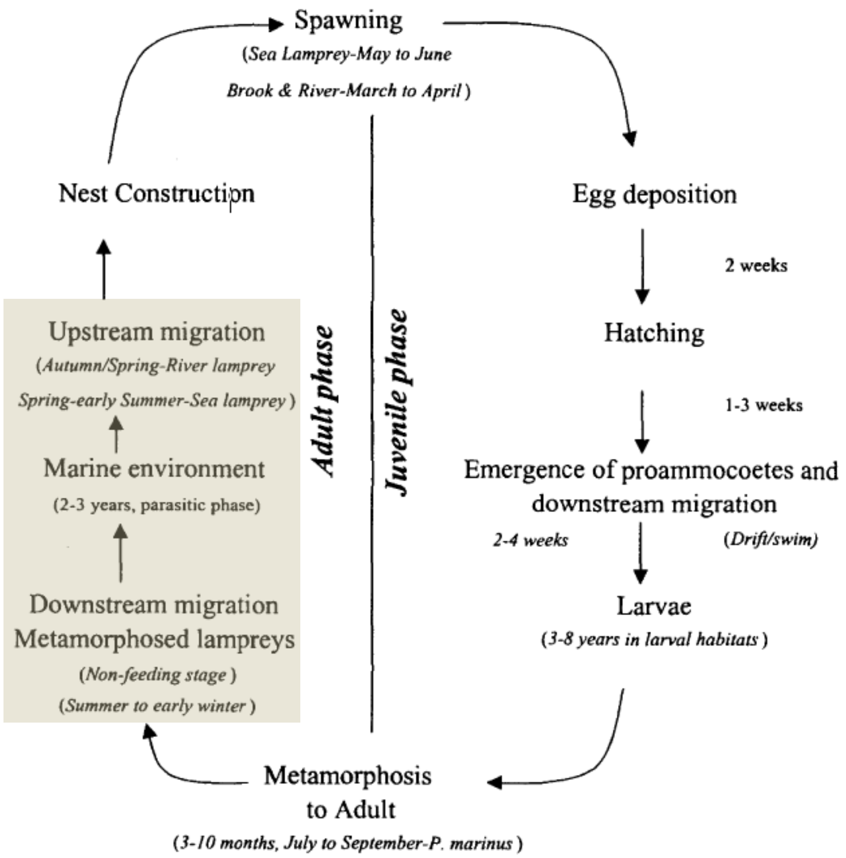

Figure 1. General life cycle of anadromous lampreys. The shadowed area indicates the phases possibly occurring in the estuarine environment. Modified from Kelly and King 2001.

20 Hatching occurs two weeks after egg deposition. Within a further one to three weeks, the larvae (called ammocoetes) emerge from the spawning substrata and drift downstream, where they burrow into silt beds in sheltered areas (Igoe *et al.* 2004). They take on the definitive larval form approximately five weeks after hatching, at which time they occupy habitats where the substrata is composed of fine sediments (Kelly and King 2001; English Nature 2003). The downstream movement of larvae is seasonal, temperature-dependent and mainly nocturnal, and the distribution of larvae within the channel depends on the gradient and flow characteristics of the river (Potter 1980a). Ammocoete burrows are characteristically found in sheltered areas of the river, up to 2.2m in depth, where the current velocity is low and organic material tends to accumulate (Hardisty and Potter 1971). At this stage, larval lampreys are non-selective filter feeders, feeding mainly on suspended material, fine organic particles and bacteria in the mud (Wheeler 1969; Beamish 1980; Mallatt 1981). The duration of this larval stage has been estimated to be at least 5-6 years for sea lamprey in English streams (Hardisty 1961; Potter 1980b), whereas a shorter larval life (4-5 years) is reported for river lamprey (Kelly and King 2001). As a result of the larval burrowing behaviour, the mortality rates for lamprey larvae are relatively low and uniform throughout the greater part of larval life, the most vulnerable stages being immediately after hatching and later during metamorphosis, when locomotory ability is low (Hardisty and Potter 1971; Potter 1980b).

21 After a period in freshwater, the larval lamprey undergoes a metamorphosis into a sexually mature non-feeding stage (young adults, called macrophthalmia). Lamprey metamorphosis usually begins during the summer (July - September) although the timing varies between catchments and years (Harvey 2003; Maitland *et al.* 1984). This transformation from ammocoetes into young adults usually occurs when ammocoetes are between 9 to 15cm in length (Hardisty 1986a,b) and takes approximately 3 months, although the time varies and can be up to 10 months (Kelly and King 2001). The newly metamorphosed lampreys migrate downstream to estuaries and coastal regions. The downstream migration is usually nocturnal, the young lampreys either burrowing or moving into protected areas that provide cover during daylight (Kelly and King 2001). The downstream migration is influenced by a marked increase in freshwater discharge (Potter 1980b), taking place between late winter and early summer for river lamprey (Hardisty *et al.* 1970; Masters *et al.* 2006). Downstream migration of river lamprey is highly variable (Maitland 1980), occurring in March-June in the Firth of Forth, whereas in the River Severn migration occurs as early as late October and as late as the following spring (Potter and Huggins 1973).

22 The marine phase of sea and river lamprey is a parasitic one, as adults feed on the body tissues and blood of various species of marine and anadromous fish. Fishes known to have been parasited by river lamprey are principally sea trout (*Salmo trutta*) and shads (*Alosa* spp.), although other possible hosts are bluefish (*Potamomus salatrix*), smelt (*Osmerus eperlanus*), sprat (*Sprattus sprattus*), herring (*Clupea* spp), powan (*Coregonus clupeoides clupeoides*) and flounder (*Platichthys flesus*) (Beamish 1980; Farmer 1980; Pickering 1993; English Nature 2003). Fish known to have been parasited by sea lamprey are salmon (*Salmo salar*), shads (*Alosa spp.*), cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), although other possible prey are basking shark (*Cetorhinus maximus*), sturgeon (*Acipenser* spp), herring (*Clupea* spp), Atlantic mackerel (*Scomber scombus*), saithe (*Pollachius virens*), hake (*Urophycis* spp), as well as harbour porpoise (*Phocoena phocoena*) and whales (*Balaenoptera* spp.) (Beamish 1980; Farmer 1980; Pickering 1993; English Nature 2003). The feeding phase lasts 1-2 years; after that lamprey stop feeding, change colour and begin to mature sexually before undertaking the upstream spawning migration.

2.1.2. CONSERVATION STATUS

23 Sea and river lamprey are listed under Annex II of the European Habitats Directive 92/43/EEC, along with several potamodromous lampreys, as species whose conservation requires the designation of Special Areas of Conservation (SACs). River lamprey also appear in Annex V, as a species whose exploitation and taking in the wild may be subject to management measures (EC 1992). European lampreys are also listed in Appendix III of the Bern Convention, signatory countries being required to take ‘appropriate and necessary legislative and administrative measures’ to ensure their protection (COE 1979). Sea and river lamprey are also UK BAP Priority Species.

2.2. Sea and river lamprey in the Humber

24 Although lamprey populations within the River Derwent SAC and other Humber tributaries are relatively well documented (Jang and Lucas 2005; Masters *et al.* 2006; Nunn *et al.* 2008; Lucas *et al.* 2009), there is a lack of information on lamprey within the Humber Estuary.

25 It is difficult to assess the spatial and temporal distribution of lampreys within the Humber Estuary as the gear selectivity from standard existing surveys is not conducive to the lamprey's spatial activity. The majority of recent surveys have been carried out during periods of limited migratory activity (CEFAS young fish surveys in September), further to this, the majority of these surveys have concentrated on a specific site for general fish assemblage assessments.

26 The most consistent recordings of lamprey within the Humber Estuary come from power station impingement data. Monitoring studies at the South Humber Bank Power Station have been carried out by IECS since 1999, initially to help assess the usage of the Humber Estuary by various fish species and quantify levels of impingement, and then more specifically focussing on lamprey impingement to provide information upon the lamprey characteristics and movements within the Humber Estuary (IECS 2000; Proctor and Musk 2001; Leighton 2008; Perez-Dominguez 2008). Lamprey impingement has also been monitored by IECS at the Elvington Water Treatment Works, situated on the River Derwent (about 19km north of the confluence between the River Derwent and the Tidal Ouse) from 2004 to 2007 (Dawes 2007). These studies provide information useful to characterise the abundance, seasonality and size of lamprey in the Humber.

27 Occasional lamprey catches have been also reported in other studies. For river lamprey, one specimen (approx. 20cm in length) was recorded during the Environment Agency's Flounder bioaccumulation survey in 2002 (N. Proctor pers. obs.), and a single occurrence (12.5cm length) was also recorded during the subtidal fish survey carried out by IECS in May/June 2010 in front of the proposed AMEP site (Burdon *et al.* 2010). Two specimens of sea lamprey were recorded during the CEFAS young fish survey carried out in September 2005 in the subtidal areas in front of Alkborough Flats and Chowder Ness mudflats (Perez-Dominguez 2008).

2.2.1. SPECIES OCCURRENCE

28 River lamprey dominated the total lamprey density in most of the impingement surveys. Sea lamprey were only impinged in 2000 (and possibly in 1999, although the two species were not distinguished during this survey), and the species was not recorded in any of the impingement surveys in 2004, 2005, 2006 and 2007 (both in the Humber Estuary and in the River Derwent).

29 The lower occurrence of sea lamprey has been confirmed by a study carried out on lamprey populations in the River Ouse catchment area in October-November 2004 (Nunn

et al. 2008). Based upon the absence of sea lamprey in larval catches and the conservation objectives set to comply with the requirement of the EC Habitats Directive 92/43/EEC (ammocoete population density 0.2m^{-2} in optimal habitat; Harvey and Cowx 2003), the authors suggested an unfavourable condition of the sea lamprey populations in the area (River Ouse catchment).

2.2.2. SEASONALITY

30 Clear seasonal patterns were recorded in the occurrence and abundance of river lamprey in the impingement catches from the surveys undertaken, providing information on the timing of the different life phases of the species in the Humber. However, the lack of data on sea lamprey in the Humber does not allow clear seasonal patterns of usage to be established, hence the seasonality reported in the literature (see Section 2.1.1) is assumed to be valid for the Humber Estuary in the absence of any locally derived data to indicate the contrary.

31 River lamprey ammocoete impingement at the Elvington Water Treatment Works (River Derwent) predominantly occurred throughout the year, although in low numbers, with occasional peaks occurring in the winter/early spring. Most of the ammocoetes impinged during the autumn period (October-November) were of a size at which metamorphosis would occur (9-12cm) and this may indicate the beginning of the metamorphosis period (Dawes 2007). Abundant autumn ammocoete populations were recorded by Nunn *et al.* (2008) in the River Ouse catchment area, with body size ranging from 2 to 12cm.

32 The high lamprey abundances recorded at the Elvington Water Treatment Works during the months of January, February, and March coincided with the high abundances of transformers (metamorphosing larvae), suggesting that peak transformation rates (at least for this part of the River Derwent) occurs during the winter/spring (Dawes 2007). Most of transformers in the autumn and winter/spring catches had a body length of between 10 and 12cm, this being the size at which river lamprey ammocoetes metamorphose into transformers before starting the downstream migration towards the estuary and the sea.

33 River lamprey migration patterns involve the movement of juvenile fish down the Humber in early summer and the spawning run of adult fish in autumn, a pattern that has been clearly captured in the lamprey impingement surveys carried out at the South Humber Bank Power Station (IECS 2000; Proctor and Musk 2001; Leighton 2008; Perez-Dominguez 2008). An example of this seasonality is shown in Figure 2, reporting the abundance of river lamprey stages from the 2004-2007 surveys (Leighton 2008).

34 Young lampreys migrating downstream usually occurred in the catches between May and August, with peak abundance recorded in June and July (IECS 2000; Proctor and Musk 2001; Leighton 2008; Perez-Dominguez 2008). Young individuals ranged from approximately 12 to 18.5cm in body size (Leighton 2008; Perez-Dominguez 2008). Most of the young lamprey showed relatively low body condition (based on Fulton's condition index), suggesting their recent non-feeding migration from freshwaters. However, a few young lampreys were recorded showing higher condition index, suggesting that they spent a recent period of time feeding, possibly this may include feeding in the estuary (hence their classification as estuarine inhabitants) (Leighton 2008).

35 Adult lamprey migrating upstream through the estuary towards the riverine spawning areas constituted the majority of the lamprey impinged during late summer and autumn months (mid July and December/early January, with peak catches usually occurring in August/September), ranging from approximately 26cm to 42cm in length (IECS 2000; Proctor and Musk 2001; Leighton 2008; Perez-Dominguez 2008). This timing of river lamprey upstream spawning migration is confirmed by historical and recent commercial

fishery catch data in the tidal River Ouse (1908-1914 and 1995-2004), with fishing occurring from October to January/February and peak catches being recorded between November and January (Masters *et al.* 2006). Adult individuals (22-38cm in size) impinged at the Elvington Water Treatment Works in the River Derwent in 2004-2007 occurred in the catches between January and May, with peak abundance in February (Dawes 2007). Similarly, Jang and Lucas (2005) recorded river lamprey adults (24-48cm in size) in the lower River Dewent spawning sites between November 2002 and February 2003 (main migration period) and in March-April 2003 (pre-spawning and spawning period).

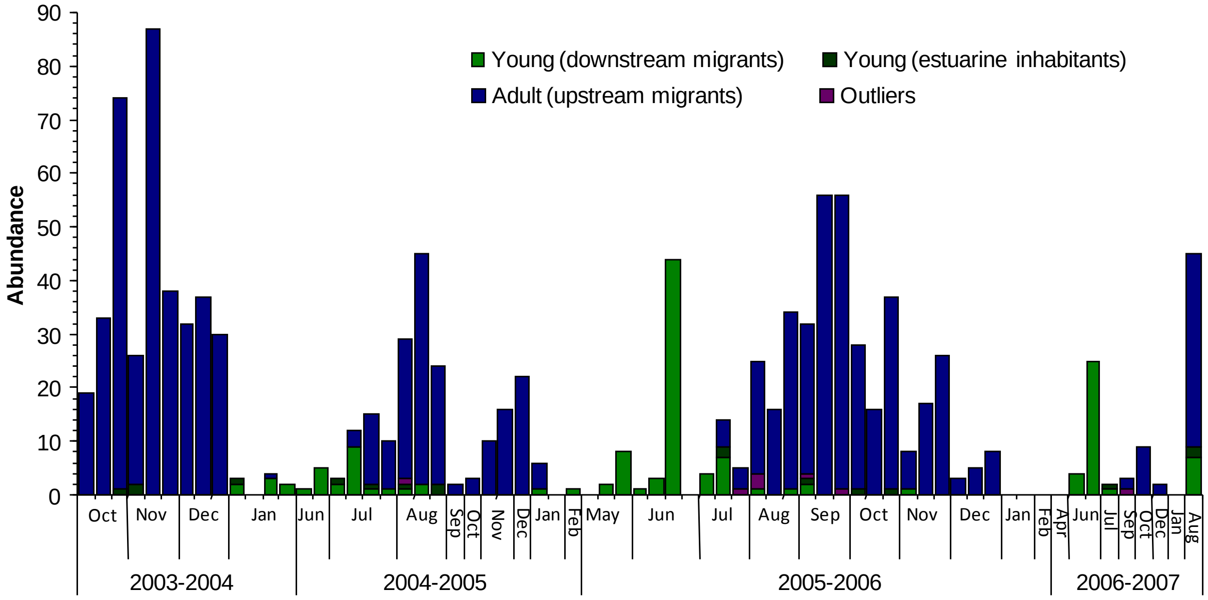

Figure 2. Total number of river lamprey impinged over 30h sampling periods at the South Humber Bank Power Station between October 2003 and August 2007 (redrawn from Leighton 2008)

2.2.3. ABUNDANCE CHANGES AND TRENDS

36 There is little historical information on the status of river and sea lamprey within the Humber Estuary other than that its current distribution indicates the Humber as an important migratory corridor to and from spawning rivers such as the Derwent (English Nature 2003). The UK populations are considered important for the conservation of these species at an EU level (English Nature 2003).

37 The Environment Agency dataset of the distribution of lamprey in rivers throughout the Humber catchment indicate that the majority of rivers within the Derwent system contain lamprey. Those that have records of lamprey include the River Nidd, River Ouse, River Ure & River Swale, however, the Environment Agency records do not discriminate between species and it is probable that these records include the brook lamprey (*Lampetra planeri*) (Davies *et al.* 2002).

38 Historic fishery data are available from commercial fishery operating in the Rivers Ouse, Derwent and Trent catchments of the Humber basin, targeting adult river lampreys during their autumn-winter spawning migration (Buckland 1878; Leaf 1908-1914; Smith 1912; Spicer 1937). A comparison of these data (1908-1914) with modern fishery catches (1995-2004) showed a substantial decrease in the river lamprey abundance in the tidal Ouse (>25,000 individuals, up to 55000 individuals in historic total catches; 10,000 to 30,000 individuals in modern total catches) (Masters *et al.* 2006). A similar trend was also

observed in the tidal Trent, the other main sub-catchment of the Humber Estuary (Masters *et al.* 2006).

39 The surveys carried out at the South Humber Bank Power Station indicate that the sea lamprey is present in the Humber Estuary in relatively low abundance, whereas the river lamprey is present in the estuarine area in moderate abundance. Nevertheless, a decrease in the abundance of impinged river lamprey has been observed over the years, particularly regarding the summer catches of young individuals during their downstream migration. Summer peak catches (over 24h sampling periods) of young river lamprey of 655 individuals and 482 individuals were recorded in 1999 and 2000, respectively, river lamprey being the dominant component of these catches (IECS 2000; Proctor and Musk 2001). The estimated impingement rate over 1year period in 1999 was 13,130 lamprey with a total biomass of 422.29kg (IECS 2000), whereas during the following sampling year 16,619 river lampreys (with a total biomass of 451.3kg) and 109 sea lampreys (with a total biomass of 10.38kg) were calculated to have been impinged (Proctor and Musk 2001). In the 2003-2007 surveys, in turn, the majority of the lamprey impinged were adults, with autumn peak abundance values ranging between approx. 45 and 90 individuals caught over 30h sampling periods. In these years the summer abundance of young river lamprey reached maximal values ranging approx. 10 to 45 individuals caught over 30h sampling periods (Figure 2) (Leighton 2008).

40 Lamprey population declines in many parts of Europe have been attributed to pollution, overfishing and physical barriers to migrations (e.g. artificial obstacles such as weirs or dams) (English Nature 2003). A major conservation priority for river lamprey (and similar species) in river catchments such as the Derwent has been identified as the increase of connectivity to multiple, larger areas of spawning habitat (Lucas *et al.* 2009). In the context of the Humber Estuary, concern has been raised as to the possible impact of fisheries on the river lamprey population, particularly when targeting spawning grounds (Masters *et al.* 2006), the life history characteristics and reproduction mode of the species could render the species more vulnerable to local extinctions (Roberts and Hawkins 1999). Also power stations and other significant water abstractors have been regarded as possible threats to migrating lamprey (Nunn *et al.* 2008).

41 However, it is of note that, based on the high larval abundance recorded in 2004 (autumn), river lamprey populations in the River Ouse catchment have been assessed as being in favourable condition (Nunn *et al.* 2008). The River Ouse catchment, in fact, is believed to support one of the most important river lamprey populations in the UK (Jang and Lucas 2005).

2.2.4. CONSERVATION IN THE HUMBER ESTUARY SAC

42 The Humber Estuary has been listed as a Special Area of Conservation (SAC) under the Habitats Directive. The two lamprey species are qualifying features, although they are not the primary reason for site selection. To ensure favourable conservation status, populations of these species must be maintained or increased over time. Draft conservation objectives for lamprey populations in the Humber Estuary SAC are set out by Natural England (2009) and reported in Table 1.

Table 1. Humber Estuary European Marine Site Conservation Objectives for sea and river lamprey species (when not specifically indicated, the objectives are valid for both sea and river lamprey species) (source: Natural England 2009).

Population Attribute (e.g. presence/absence, population size or assemblage score)	Site Specific Target
Population - Age structure (*Lampetra* sp. only)	For samples of 50 or less, at least two distinct size classes should normally be present. If more than 50 ammocoetes are collected, at least three size classes should be present.
Population - Distribution within catchment	Lampreys should be present at not less than 2/3 of sites surveyed. As a minimum, there should be no reduction in the distribution of ammocoetes within the catchment. Where barriers to migration or pollution issues are thought to be a problem, the population should be classed as being in unfavourable condition and targets for an appropriate increase should be set.
Population - Ammocoete density	*Lampetra* spp: Optimal habitat: >10 m^{-2}, Chalk streams >5 m^{-2}, Overall catchment mean:>5m^{-2} *Petromyzon*: Ammocoetes should be present in at least four sampling sites, each not less than 5 km apart.
Population - Spawning activity (sea lamprey only)	No reduction in extent of spawning activity year on year
River morphology	No artificial barriers significantly impairing adults from reaching existing and historical spawning grounds. Maintain the characteristic physical features of the river channel, banks and riparian zone
Negative indicators	No stocking of other fish species at excessively high densities

Population Attribute (e.g. presence/absence, population size or assemblage score)	Site Specific Target
Water quality	Biological GQA Class: b/B Chemical GQA Class: B Dissolved Oxygen (DO): - DO should not fall below 2mg/l - DO should not fall below 5mg/l for more than 5 consecutive days - Following a period of DO of less than 5mg/l there should be at least 2 consecutive days where DO remains above 5mg/l Suspended solids: Annual mean <25 mg/l
Flow	As a guideline, flow should be at least 90% and not more than 110% of the naturalised daily flow throughout the year.
River morphology	Maintain the characteristic physical features of the river channel, banks and riparian zone

3. IMPACTS OF AMEP ON SEA AND RIVER LAMPREY

3.1. Assessment methodology and criteria

43 The assessment methodology used in this document follows a broadly common approach based around the Guidelines for Ecological Impact Assessment in Britain and Ireland (Marine and Coastal) published by the Institute of Ecology and Environmental Management (IEEM 2010).

44 Given the biological and taxonomical similarity between the river and sea lamprey, impacts were assessed simultaneously for the two species, unless clear information on their different sensitivities was available from literature.

45 The assessment was carried out separately for the different project phases (construction and operation). The criteria in the assessment were based on the combined evaluation of the magnitude of effects and the sensitivity of lamprey species (receptors).

46 In order to assess the magnitude of an effect, its spatial extent, duration and scale were taken into account. This information was gathered from available literature and previous assessments of similar effects, taking into account the technical information on the development structures and methodologies.

47 The assessment of the sensitivity of lamprey species was based on its importance and recoverability. This information was mainly derived from the available scientific and grey literature and, where possible, from additional assessments of impacts on the same or similar receptor.

48 The evaluations of the magnitude of effect and of the sensitivity of receptor were then combined in a final assessment of the impact significance, following the matrix in Table 2. An impact is defined as a change (which can be positive or negative) that occurs as a consequence of an activity. Where the significance was higher than minor (moderate or major) this is considered to be a potentially significant effect. It should be noted that significant effects need not be unacceptable or irreversible.

49 The Conservation of Habitats and Species Regulations 2010 (the Habitats Regulations) require that where a proposed development has the potential to have a likely significant effect on a Natura 2000 site then an Appropriate Assessment (AA) must be conducted by the Competent Authority. The AA must consider the implications for the status of the integrity of the constituent features of the European Site in respect of any plan or project which is not directly connected with or necessary to the management of the European Site for conservation purposes and which is likely to have a significant effect on the European Site either alone or in combination with other plans or projects. Given that sea and river lamprey are features of interest for both the lower River Derwent tributary and the Humber Estuary SACs, the assessment of impacts on lamprey from the proposed AMEP development will inform the AA.

Table 2. Matrix for Significance of Impact

	Sensitivity of Receptor (based on importance and recoverability)				
Magnitude of Effect (based on spatial, duration and scale of effect)		**Very High**	**High**	**Medium**	**Low**
	Very High	Major	Major	Major	Moderate
	High	Major	Major	Moderate	Minor
	Medium	Major	Moderate	Moderate	Minor
	Low	Moderate	Minor	Minor	Negligible
	Negligible	Minor	Negligible	Negligible	Negligible

3.1.1. CONSTRUCTION PHASE

50 The impact analysis in this phase emphasises acute impacts arising from the quay construction activities. The impacts have been scored taking account of the final engineering plan and information from the various other assessments (hydrodynamic and sediment regime, noise, water quality, navigation, expected dredging needs, aquatic ecology, etc.).

51 Impact prediction has relied on quantitative elements wherever this was possible. Where the available information did not allow quantification, professional judgement has been applied.

3.1.2. OPERATIONAL PHASE

52 The assessment of the operational phase has been conducted on the basis of the impact of the presence of the functioning quay and the associated increased vessel traffic.

53 The impact analysis focuses on chronic pressures such as routine vessel traffic and permanent habitat loss rather than acute effects that comparatively would be less important during this phase.

3.1.3. CUMULATIVE AND IN-COMBINATION IMPACTS

54 Cumulative impact assessment includes impacts that result from incremental changes caused by other past, present or reasonably foreseeable actions in the area, such as other port/harbour developments, together with those relating to the development project. In-combination impact assessment addresses specifically those cumulative impacts having a significant effect on the status of the integrity of the constituent features of a European Site (English Nature 2001), given that the receptors (sea and river lamprey) are features of interest for the lower Derwent tributary and Humber Estuary SACs. The assessments of cumulative and in-combination impacts largely overlap, hence they have been treated together and have been addressed under the general term of cumulative impacts.

55 As such the cumulative impact assessment addresses situations where predicted impacts of the AMEP construction and operation could interact with impacts from other industry sectors within the same region and impact the status of the lamprey populations in the Humber Estuary and the River Derwent SACs, as well as in the other tributaries. This may be through direct effects or spatially/temporally separated impacts which may result from additional pressures (e.g. noise, dredging and land reclamation) arising from surrounding projects and future development plans.

3.2. Impact assessment

56 Different sources of impact on lamprey have been identified. The potential impacts, related to these different sources are presented separately for the different project phases.

57 The assessment of impacts which are likely to arise during construction of the proposed development has taken into account the different activities which are likely be carried out during this project phase, such as dredging, dredge disposal, quay construction and construction run off.

58 With regard to the operational phase, the assessment has accounted for the potential impacts arising from the physical presence of the quay, the increased vessel presence in the area, maintenance dredging activities and changes in water quality due to discharges.

59 As different activities may produce impacts of similar nature (e.g. underwater noise from dredging and piling activities during construction), the assessment has been carried out by type of impact.

3.2.1. CONSTRUCTION PHASE

NOISE AND VIBRATION

60 During construction activities in the AMEP site, a direct effect on lamprey might arise from the noise and vibration mainly associated to piling activities and dredging. Other sources of noise, such as for example, increased vessel traffic during construction activities are unlikely to contribute significantly to background noise (which might be relatively high, due for example to the large volumes of shipping already occurring in the area) or to provoke significant effects on marine fauna (Nedwell *et al.* 2003).

61 Dredging emits continuous broadband sound during operations, mostly in the lower frequencies, most energy being emitted at frequencies below 500Hz. Source levels range from 160 to 180dB re 1µPa at 1 m (maximum ~ 100Hz) (Götz *et al.* 2009). It is in respect of pile-driving that the greatest levels of noise are likely to arise, being predominantly low frequency underwater noise, that can travel large distances and that can lead to acute short term disruption of the marine fauna (Hiscock *et al.* 2002; Nedwell *et al.* 2007, 2011).

62 The frequency spectrum of piling noise ranges from less than 20Hz to more than 20,000Hz with most energy around 100 - 200Hz (Götz *et al.* 2009). Piling source levels may vary depending on the diameter of the pile and the method of pile driving, percussive impact or vibropiling. During the AMEP construction, piling will be undertaken in overlapping phases for the different types of piles. The front wall of the quay (2.4m piles) will be driven using a large hammer, and the concrete piles behind using a slightly smaller hammer. The front wall construction is expected to involve a period of 6 months for the piling works, operating 16 hours a day (6am-10pm), 6 days a week. The other piling operations of the concrete piles and sheet piling may continue over the full length of the construction period of two years. However, it is the piling of the front wall that is considered the most significant phase of piling in terms of underwater noise, given that it will be undertaken using the largest piling hammer and noise will be able to propagate unobstructed into the estuary. According to the worst case scenario accounted for piling noise construction (Chapter 10 of the AMEP Environmental Statement), a sound energy of 188dB re 1µPa^2 -sec (Sound Exposure Level, SEL measured at 25m from the pile, corresponding to a peak pressure of 212dB re 1µPa) has been estimated associated to each single pile strike from a 2.4m diameter Cast-in-shell Steel (CISS) Pile driven with a 500-Kilojoule Hydraulic Hammer (California Department of Transportation 2009). The overall sound pressure associated with the piling activity will be a cumulative energy depending on the number of pile strikes needed to install a pile and on the number of piles installed (leading to a scenario of 7,000 pile strikes per day; Chapter 10 of the AMEP Environmental Statement). The impact zone for hearing damage will depend on the cumulative SEL levels, the propagation/attenuation of underwater noise in relatively shallow waters as well as on the hearing ability of the species under examination (California Department of Transportation 2009).

63 There is a lack of information available on hearing in lamprey and no reported audiograms exist for these species. Given that they both lack any specialist hearing structures and that their ear is relatively simple (they have no swim bladder or anatomical structure tuned to amplify sound signals), they are considered to be hearing generalists, with a maximum hearing range to no more than several hundred Hz (Popper 2005). Therefore behavioural or physiological effects on lamprey are usually considered likely to occur only when the organism is very close to a powerful noise source (Popper 2005; Popper and Hastings

2009). However, the assumption of lamprey being a hearing generalist fish is based on the use of very limited morphological data, and Popper (2005) acknowledged the considerable importance for data to be obtained on the hearing of these species. The understanding of the hearing ability of lamprey is complicated by the fact that they do not have otolith organs and no known work has been undertaken on the response of lamprey to sound in relation to their statoliths or labyrinth organs. Work has been undertaken on cephalopods however, which also have statolith organs for the detection of linear accelerations including gravity (Packard *et al.* 1990). This investigation confirmed that cephalopods could detect the kinetic component of low frequency sounds and it is believed that the statoliths are the sensory organs involved (Packard *et al.* 1990). Based on these results and on the similarity of hearing organs, there is potential that lamprey may also be able to hear infrasound. Lenhardt and Sismour (1995) carried out experiments on sea lamprey and detected a startle response to frequencies between 20 and 100Hz. However, the response is likely to be associated more to vibration than waterborne noise, as the click sound was delivered by a submerged vibrator through the tank wall where lamprey were attached. Startles while swimming were rare suggesting that direct contact with the vibrating surface was needed to trigger the reaction. The river lamprey was included in a study on the effect of a playback system (with emission frequencies between 20 and 600Hz) in reducing estuarine fish intake rates at a power plant cooling water inlet (Maes *et al.* 1999, 2004). No significant reductions in river lamprey catches were observed. The absence of a significant response of lamprey resulting from the above mentioned studies might suggest a low hearing ability of these species at a frequency bandwidth of 20 to 600Hz. However, the level of sound pressure emitted during the experiment carried out by Lenhardt and Sismour (1995) is likely to be low. In turn, the results obtained by Maes *et al.* (1999, 2004) are likely influenced by the very low number of lamprey in the catches (0 to 5 individuals per catch). Therefore, these studies cannot be considered as conclusive in demonstrating low hearing ability of lamprey species. According to the available information, the possible hearing range of lamprey is likely to overlap with the sound emissions from dredging and piling activities. However no clear evidence on the actual hearing sensitivity of the species is available, particularly at their migrating active phase. The species might also be affected by vibration arising from construction activities, although no information on the sensitivity to vibration of the species while swimming or resting is available.

64 Considering the life cycle of sea and river lamprey and their occurrence in the Humber Estuary (Section 2), and the timing of piling activities (6 months, excluding winter months), it is likely that the period of impact will overlap with the period of higher vulnerability of lamprey, that is during their summer downstream migration (as young individuals, 12-18.5cm in length), peaking in June-July, and/or during the late summer-autumn upstream spawning migration (as adult individuals, 26-42cm in length), peaking in August-September. An earlier upstream migration, in spring to early summer, is reported for sea lamprey (Hardisty and Potter 1971), although no records of it are available from impingement data in the Humber (IECS 2000; Proctor and Musk 2001; Leighton 2008; Perez-Dominguez 2008).

65 In the present assessment, the possible effect of piling noise on lamprey has been quantified by considering the assessment of such impact carried out for hearing generalist fish in Chapter 10 of the AMEP Environmental Statement. This assessment is derived from the sound propagation calculations following the Fisheries Hydroacoustic Working Group predictive model provided in California Department of Transportation (2009). The calculations are based on the worst case scenario described above and on the recommended interim sound exposure criteria for fish as threshold for physical injury (peak pressure of 206dB re 1µPa for all size of fish, cumulative SEL 187dB re 1µPa^2 -sec for fish ≥2g; Fisheries Hydroacoustic Working Group 2008) (see Chapter 10 of the AMEP

Environmental Statement for details on the model parameters). These criteria represent the latest available standards agreed by the U.S. Federal Highway Administration, NOAA Fisheries, U.S. Fish and Wildlife Service, the Department of Transportation from California, Oregon and Washington (Fisheries Hydroacoustic Working Group 2008). As a result, the calculations indicate that the noise pressure arising from piling activities (under the worst case scenario) attenuates to levels below the threshold for physical injury in fishes at a distance of approx. 7.3km from the piling. Therefore, fish may experience damage over time if they are present within 7.3km of the piling for substantial periods of time, this distance exceeding the width of the estuary at the location of AMEP.

66 This calculation is based on the use of a large hammer (500kj) on 2.4m diameter CISS piles. It has been hypothesised that the use of a smaller hammer (with similar piles) might reduce the impact, by reducing the noise level. Although there are no information available on the noise produced by using smaller hammer (with similar piles characteristic), there are data indicating that a larger hydraulic hammer (1780kj) applied to piles of similar size led to an increase of max 2dB re 1µPa at 200m (California Department of Transportation 2009). If the same applies to the use of a smaller hammer size (on similar piles and constrained by technical issues), a similar reduction of sound exposure level would lead to a decrease of the area of impact from 7.3km to 5.4km, this area still exceeding the width of the estuary at the location of AMEP.

67 This represents a worst case scenario, as the area of impact could be reduced by the movement of fish further away from the noise source, leading them to experience a lower cumulative sound energy. Furthermore, the latest available recommended interim sound exposure criteria for fish used to obtain the above estimate is derived for hearing generalist fish having swim bladders, hence a likely lower impact zone can be anticipated on lamprey (given the absence of a swim bladder in these species, although other injuries like damage to kidney, liver and auditory tissue cannot be excluded). In addition, the above threshold setting represents a rather conservative standard, as a peak value of around 180 dB re 1 µPa seems to have gained wide acceptance to identify an upper limit of sound pressure above which injury likely occurs. However, the uncertainty of the above model prediction regarding the possible injury impact zone highly increases at distances >1,000m (due to the uncertainty on predicting audibility at those distances) (California Department of Transportation 2009). This poses a spatial limitation to the reliability of the model prediction within a distance of 1,000m from the pile driving activity, although it does not exclude a possible impact at distances higher than 1km. Furthermore, it must be considered that, although the model takes account of the propagation of underwater noise based on piling in relatively shallow water, it does not account for reflections from obstacles and from the estuarine banks, which might modify the levels of exposure at distance.

68 The hearing loss has been anticipated to be temporary and reversible (TTS) in a portion of the fish subjected to impact, with their original hearing being fully restored upon cessation of the activities. Also a more permanent hearing loss has been anticipated, particularly in smaller specimens (e.g. juveniles migratory fish) leading to a reduction of their overall fitness. Fish mortality might also occur, although it is likely to occur if fish are sufficiently close to the source (within tens of meters), and fishes further from the source are not likely to be killed (California Department of Transportation 2009). Exposure of migratory fish (e.g. Atlantic salmon) to piling noise has been anticipated as of relatively short duration, with a reduction of the accumulated sound exposure as a function of the fish's transit speed through the area and its location in the channel in relation to the piling activity (Chapter 10 of the AMEP Environmental Statement).

69 As regards lamprey, they show an active swimming behaviour during migrations, and no feeding occurs in most cases, although possible pelagic parasitic feeding in the estuary has been suggested during downstream migration (Leighton 2008). Ultrasonic tagging experiments with teleosts have shown that migrating fish seldom follow a strictly linear course although directionality in their pattern of movement is generally apparent (Poddubny 1967; Hasler *et al.* 1969; McCleave and Horrall 1970; Yuen 1970; Dodson *et al.* 1972). The absence of a hydrostatic organ (swim bladder) and paired fins (leading to an anguilliform-like propulsion) makes lamprey relatively poor swimmers, with average swimming speed of less than 0.1m/s calculated for adult sea lamprey during upstream migration also in low flowing rivers (William and Beamish 1979). Quintella *et al.* (2009) indicated maximum swimming velocities close to 3.9 m/s in sea lamprey, although they can be maintained for very short periods, and William and Beamish (1979) reported that sea lampreys could not swim for more than 30 minutes at 0.3 m/s. It is likely that in the estuarine area lamprey would take advantage of the tidal currents during their migration upstream and downstream, as this is a common behaviour of fish migrating into estuaries (McCleave *et al.* 1984; Hill 1995). However, it must be considered that most of the piling noise impact will occur during daytime (piling works are scheduled between 6am and 10pm), when migrating lamprey are reported to be resting under rocks and riverbanks, the main migration (both upstream and downstream) occurring at night (Section 2). This might enhance the duration of their exposure to the noise impact during daytime. Therefore, given the poor swimming ability of lamprey species and their daytime sedentary behaviour, it is likely that the duration of impact on lamprey would be longer than the one estimated for other migratory fishes (e.g. Atlantic salmon; Chapter 10 of the AMEP Environmental Statement).

70 The abundance of lamprey impinged at the South Humber Power Station, at the edge of the main channel (the intake head being situated about 1.3km from the shore at low tide), would suggest this area as a possible preferential route for migration, as it would provide a quick access to deeper waters (channel), to take advantage of favourable tidal currents, and to adjacent shallow subtidal areas (where the water current is lower) when tidal currents are opposite to the migration stream. Although there is no evidence of such a behaviour in the estuary (all the studies on swimming behaviour have been carried out in stream habitats), localised movements are commonly observed during fish migrations into estuaries to benefit from a net active transport following tidal currents (McCleave et al. 1984; Hill 1995). Therefore, unlike other fish species (e.g. flounder), estuarine intertidal and shallow subtidal areas do not appear to be essential habitats for lamprey, as their parasitic feeding habit is associated with large pelagic marine hosts and their spawning and nursery (ammocoete) habitats occur in the freshwater catchments. However, the usage of shallow subtidal estuarine areas close to the AMEP site by resting individuals during daytime cannot be completely excluded, as no data either confirming or refuting this behaviour in the estuarine environment are available.

71 The assessment has taken into account also the lamprey abundance in the estuary in the context of previous piling campaigns which occurred in the area interested by the proposed AMEP development. These included the construction of a new jetty at the Humber International Terminal (HIT, Port of Immingham) in 1999/2000 and of a series of new berths at the Humber Sea Terminal (HST, North Killingholme) in 2000, 2003 and 2007. If an effect of these piling activities on migrating lamprey has occurred, this might be reflected particularly on summer juvenile catches at Stallingborough impingement, being the power station intake located after the possible area of impact along the downstream migration. A decrease in the abundance of impinged river lamprey has been observed over the years (Section 2, Figure 2), particularly regarding the summer catches of young individuals during their downstream migration. Although this could be the result of an impact from the piling noise, other factors might have contributed to the lamprey

decrease, e.g. a decrease in recruitment levels in the river or other impacts during the downstream migration, but the available data do not allow quantify them. Therefore, putting the impingement levels in the context of previous piling campaigns does not allow us to support or refute the hypothesis of a causal relationship between the lamprey abundance decrease in the estuary and historic piling activities.

72 Given the above considerations, and based on the absence of clear evidence on the species hearing ability, on the uncertainty on the lamprey migrating behaviour in the estuarine areas, and on the (complete or possibly partial) temporal overlap between the main piling activities and the species migration seasons through the estuary, a precautionary approach has been adopted for the impact assessment of noise and vibration on lamprey. Therefore, the potential impact arising from this pressure during construction has been assessed as of a low to possibly medium magnitude, the receptor has been assessed of medium sensitivity, and the significance of the impact would be minor to possibly moderate (hence possibly significant).

WATER ABSTRACTION

73 The quay construction in the AMEP site will involve hydraulic dredging and the use of the rainbowing technique to backfill the area between the existing flood defence and the new quay with imported hydraulic fill. In both cases, water will be abstracted (with sediments during dredging and to fluidise sediments for rainbowing), and the impingement of fishes in the vicinity of the suction pipe might occur during abstraction. This might lead to a direct impact (mortality) on migrating lamprey, due also to their general moderate-low swimming performance (*sensu* Maes *et al.* 2004).

74 Power stations and other significant water abstractors (e.g. for electricity production or industry) have been regarded as a possible threat to migrating lamprey, although, despite the relatively high impingement rates in the Humber, river lamprey populations in the upstream River Ouse catchment have been assessed in favourable condition (Nunn *et al.* 2008). A large power station may abstract up to 40m^3/s or more during peak load (e.g. the South Humber Bank Power Station requires a cooling water input of approx 25m^3/s; Proctor and Musk 2001).

75 Although no quantitative data on the water intake occurring during sediment dredging and rainbowing activities are available, a lower intake rate is roughly comparable to power plant intakes, probably within an order of magnitude. In addition, the potential impact would be limited in space (around the suction pipe head) and time, hence it has been assessed of low magnitude. The impact would lead to a main mortality effect on lamprey, and no recoverability is anticipated.

76 Given the above considerations, the potential impact on the receptor arising from this pressure during construction has been assessed as having high sensitivity, and the significance of the impact would be minor.

HABITAT DISTURBANCE

77 Construction activities in the AMEP site might have an indirect effect on lamprey through the alteration of the benthic and pelagic habitat as a result of sediment plumes from dredging and dredge spoil disposal as well as water quality changes due to construction run off and site drainage.

78 The construction of the AMEP will require a significant capital dredging of both erodible (soft clay, silt, sands and gravels) and unerodible (glacial till) material. This will be dumped at different disposal sites within the Humber, and the resulting sediment plumes would lead to an increase in turbidity. The highest impact is likely to arise at the disposal

site for erodible material, as it is estimated that the unerodible material will add a negligible amount to the background suspended sediment concentrations (Chapter 8 of the AMEP Environmental Statement). It is estimated that the majority of erodible material will settle on the bed of the estuary immediately around the disposal site (within a radius of approx. 100m), while a proportion of the finer material will be dispersed away from the disposal site with the currents. According to the sediment plume hydrodynamic modelling carried out for Chapter 8 of the AMEP Environmental Statement, the peak increase of suspended sediment concentrations will increase up to 80-100mg/l by the end of the disposal programme, with possible short lived peaks of 300-400mg/l above ambient at the dumping site. However, this increase will be of relatively short duration, as suspended sediment concentrations will quickly decrease upon cessation of sediment release, following dispersion within the estuary and through outgoing tides. Sediment plumes will also occur from dredging activities at the AMEP site, but they are likely to be relatively small compared to the dredge disposal plume due to the much smaller quantity of sediment suspended (orders of magnitude less than that through direct disposal). High turbidity background levels are common in the Humber Estuary, it being one of the most turbid estuaries in Europe. Maximal values have been reported of approx. 5,000mg/l (Marshall and Elliott 1998), and recent measurements at the Humber Sea Terminal (to the north of the AMEP) give a range of 200mg/l to 1,600mg/l. Therefore the increase in sediment concentration following dumping and dredging activities is anticipated to be within the general range of suspended sediment concentrations found in the Humber. Furthermore, these turbidity values are much lower than those having a physiological effect on fish (>14000mg/l; Marshall and Elliott 1998).

79 Dredging and dredge disposal activities might result also on a reduction of dissolved oxygen concentrations in the water. However, good dissolved oxygen concentrations are currently recorded in the Humber Estuary, and the reduction in dissolved oxygen concentration due to sediment resuspension is expected to be localised and short term (Jabusch *et al.* 2008). Therefore oxygen levels are unlikely to be reduced to potentially adverse levels to fish fauna or to act as a barrier to lamprey migration.

80 Construction site drainage and run-off may also reduce water quality as non-contaminated drainage and drainage containing oil or maintenance products may run off into the marine environment resulting in gully formation and local water quality changes. However water quality changes from construction run-off are likely to be limited to the immediate area surrounding the quay and any contaminants will quickly become diluted to background levels. Furthermore, in-built mitigation measures will be undertaken, such as for example the use of oil interceptors where a high risk of oil spillage exists.

81 The impacts to lamprey from the above habitat disturbance may result in behavioural changes, for example temporary avoidance of areas with low water quality due to run-off or increased turbidity. In general, the lampreys are considered “intermediate” to “intolerant” of pollution and habitat disturbance (Grabarkiewicz and Davis 2008) although toxicity tests indicated that lamprey have similar or lower sensitivity to other fish such as rainbow trout or other salmonids (Windward Environmental LLC 2009). However the available data on lamprey tolerance usually refer to larval (ammocoetes) or spawning adult stages in the riverine environment and no information are available for the migrating phases in the estuary. However, it is expected that, being the estuarine environment a common migratory pathway for lamprey, these are likely adapted to the temporary exposure to estuarine environmental conditions, including relatively high water turbidity. The habitat disturbance following the AMEP construction activities will be localised and short-term and lamprey are expected to avoid any area affected by disturbance and to be able to return once the disturbance has ceased. Therefore it is considered that habitat

disturbance is unlikely to have long-term impacts on lamprey and on their migration routes.

82 Given the above considerations, the potential impact arising from habitat disturbance on lamprey has been assessed as of <u>low magnitude</u> and the receptor has been assessed of <u>medium sensitivity</u> (based on a precautionary approach, given the lack of clear evidence). Therefore <u>the significance of the impact would be minor.</u>

PERMANENT HABITAT LOSS

83 Construction activities in the AMEP site might have an indirect effect on lamprey through the loss of benthic and pelagic habitat as a result of dredging and dredge spoil disposal as well as the overall quay footprint and the quay physical presence on the estuarine bank.

84 Although no information is available on the intertidal occurrence of lamprey in the estuary (to our knowledge no records of lamprey have been reported in intertidal surveys carried out in the Humber), the usage of intertidal habitat cannot be excluded. However a strict association of the species with this habitat is considered unlikely. Therefore, the habitat loss assessment has been focused on the subtidal habitat. It is also anticipated that, for the reasons mentioned above, no beneficial effects are expected from the compensation site.

85 Given that the lamprey usage of the estuary is primarily as a pathway of migration and the possible usage of this environment as a feeding ground for young individuals is restricted to the pelagic environment (parasitic pelagic habit), the pelagic habitat is considered as a primary essential habitat in the estuary. However, the usage of lamprey of the benthic habitat during daytime in subtidal areas cannot be excluded, given that a nocturnal migrating behaviour and a resting sedentary behaviour in riverbanks during daytime has been reported for sea and river lamprey, although no direct evidence of such behaviour is available for the estuarine area.

86 Capital dredging during construction activities will cause a direct loss of benthic subtidal habitat through sediment removal in the project area. It is estimated the total volume of dredged sediment will amount to up to 1.6Mm^3. A direct habitat loss will also occur under the quay footprint, being the quay structure developed on existing subtidal areas (18.35ha), as well as under the footprint of the dredge disposal sites. According to the figures provided in Chapter 10 of the AMEP Environmental Statement, the overall subtidal project footprint is estimated to be small compared to the overall subtidal estuarine habitat (16,800ha, Hemingway *et al.* 2008).

87 Given the above considerations, the impact of benthic habitat loss on migrating lamprey has been assessed of <u>low magnitude</u> and the receptor has been assessed of <u>medium sensitivity</u>. Therefore <u>the significance of the impact would be minor.</u>

3.2.2. OPERATIONAL PHASE

NOISE AND VIBRATION

88 During operation a direct effect of AMEP on lamprey might arise from the noise and vibration mainly associated with the increased vessel traffic and maintenance dredging activities.

89 The noise associated with increased vessel traffic is likely to be long term, although vessel movements for the AMEP site will be intermittent. It is unlikely that it will contribute significantly to existing levels of underwater noise or to provoke significant effects on

marine fauna (Nedwell *et al.*, 2003), also given that the Humber Estuary is among the country's busiest trading estuaries and shipping is widespread.

90 The noise emission associated with maintenance dredging will be as described in Section 3.2.2 and a potential impact is anticipated on lamprey. However it will be temporary and intermittent and its overall magnitude will be lower than that assessed for the construction works phase and similar to current levels experienced in the area.

91 Given the above considerations, the potential impact arising from noise and vibration on lamprey during the AMEP operation has been assessed of negligible magnitude, the receptor has been assessed of medium sensitivity (based on the precautionary approach described in Section 3.2.1) therefore the significance of the impact would be negligible.

HABITAT DISTURBANCE

92 The AMEP operation might have an indirect effect on lamprey through the alteration of the benthic and pelagic habitat as a result of sediment plumes from maintenance dredging and dredge spoil disposal as well as water quality changes due to planned discharges and emissions from vessels and the quay.

93 Impacts from the sediment plume caused by maintenance dredging and dredge disposal will be the same as those from dredging and disposal activities required during construction. However it is anticipated that the duration and volume of elevated suspended sediment levels will be reduced and the impact will be temporary and intermittent as maintenance dredging is only required periodically. Hence the magnitude of the impact will be lower compared to that one assessed for the construction phase.

94 Run-off from the quay might lead to a water quality impairment (high suspended solids load) in the immediate vicinity of the quay. Run-off from the quay or vessels is unlikely to be contaminated, as a result of the quay containment facilities, and, although unpredictable, its impact is likely to be local, temporary and intermittent.

95 Given the above considerations and the sensitivity of lamprey assessed in Section 3.2.1, the potential impact arising from habitat disturbance on lamprey during the AMEP operation has been assessed of negligible magnitude, the receptor has been assessed of medium sensitivity (based on the precautionary approach described in Section 3.2.1), therefore the significance of the impact would be negligible.

BARRIER TO MIGRATION

96 The presence of the AMEP quay might be a physical obstacle leading to disruption of lamprey migration through the estuary. This might constitute a significant impact, particularly on upstream spawning migration (Lucas *et al.* 2009).

97 Access to riverine spawning localities is regarded as a major conservation priority for river lamprey and similar species, as this has been indicated as the main causal factor of larval recruitment variability observed in the River Derwent SAC (Lucas *et al.* 2009). The presence of physical barriers to migrations (e.g. artificial obstacles and anthropogenic barriers) influence recruitment success of some lamprey populations in mainland Europe and a possible similar impact is reported for the Ouse catchment (Nunn *et al.* 2008). It possibly acts as a bottleneck, leading to population decline (Wilcox and Murphy 1985; Law and Dickman 1998). However, most of the data on the effect of physical barriers to lamprey migration relate to the riverine environment, where the presence of barrages, dams, weirs, sluices and even small-scale barriers can dramatically reduce the longitudinal connectivity of rivers, potentially affecting the distribution of lamprey spawning

habitats and restricting the species ability to utilise upriver areas (Lucas *et al.* 2009). No similar studies have been conducted in the estuarine environment.

98 It is expected that the quay at the AMEP site will be developed on existing intertidal and subtidal areas (32.88 and 18.35ha, respectively). The quay structure will be 1,200m long and will extend out approx. 500m from the actual shoreline (to -9m CD), thus extending for less than 12% of the estuary cross-sectional width in the development area (approx. 4.5km). The quay structure at the AMEP site will then constitute a small physical barrier and, given that abundant migrating lamprey have been recorded on subtidal areas farther from the shore (>1km), it is unlikely that the quay structure will significantly affect the lamprey migration.

99 Given the above considerations the potential impact on lamprey migration arising from the physical presence of the quay structure at the AMEP site has been assessed of <u>negligible to low magnitude</u>, the receptor has been assessed of <u>high sensitivity</u>, therefore <u>the significance of the impact would be negligible to minor.</u>

3.2.3. MITIGATION

100 Mitigation measures should be undertaken to avoid, reduce or mitigate the potentially significant impacts on lamprey associated with the proposed AMEP development.

101 According to the assessment above, the only potentially significant impact on lamprey will arise from noise and vibration emissions during the development construction. This impact has been assessed of minor to possibly moderate significance. It is of note that the possible significance of the impact arises mainly from the adoption of a precautionary approach, given the lack of clear evidence on the specie’s hearing ability and on the uncertainty on the lamprey migrating behaviour in estuarine areas, as well as the (complete or possibly partial) temporal overlap between the main piling activities and the species migration seasons through the estuary.

102 The precautionary principle is relevant in the event of a potential risk, even if this risk cannot be fully demonstrated or quantified or its effects determined because of the insufficiency or inconclusive nature of the scientific data (COM 2000). One of the primary foundations of the precautionary principle, and globally accepted definitions, results from the work of the Rio Conference, or "Earth Summit" in 1992. Principle #15 of the Rio Declaration notes: "*In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*". This definition explains the idea that scientific uncertainty should not preclude preventative measures to protect the environment. Activities that present an uncertain potential for significant harm should be subject to best technology available requirements to minimise the risk of harm unless activity is proved to present no appreciable risk of harm. However, the use of "cost-effective" measures indicates that costs can be considered. In addition, according to the Guidelines for Applying the Precautionary Principle to Biodiversity Conservation and Natural Resource Management (as approved by the 67th meeting of the IUCN Council, 14-16 May 2007), in applying the precautionary principle measures should be adopted that are proportionate to the potential threats. Therefore, precautionary mitigation measures should be weighted based on their stringency (and their associated costs), as well as on the seriousness and irreversibility of the potential threat and the degree of uncertainty (e.g. a BATNEEC and BPEO approach).

103 Technical measures are available to mitigate or attenuate underwater noise created during marine construction projects involving pile driving. These include using soft-start

procedures, pile hammer cushions, flap anchors, acoustic deterrent devices, and a vibratory hammer whenever possible. Noise impacts from dredging or general increased shipping activities could be reduced by choice of vessels and their careful manoeuvring and positioning. Likewise current improvements in propulsion technology are resulting in quieter vessels that produce less overall noise which could offset some expected increase.

104 The timing of construction activities to avoid the species of concern is usually the most effective means of mitigating harm. Considering the life cycle of sea and river lamprey and their occurrence in the Humber Estuary, it is likely that lamprey will be most vulnerable to noise disturbance during the summer and autumn seasons, the downstream migration peaking in June-July and the upstream spawning migration peaking in August-September. Therefore a useful window when there is reduced use by lamprey is likely to be winter and spring (an earlier upstream migration, in spring - early summer, is reported for sea lamprey, although no records of it are available from impingement data in the Humber). Outside this seasonal winter-spring window, night-time can be considered a useful window, when the mobility of lamprey is higher, thus reducing its exposure to the impacts, although this measure should be supported by monitoring studies aiming at clear out the actual migration behaviour of lamprey in the estuary.

105 However, the application of phased timing as a mitigation measure during construction can be applied for a range of species, including in this proposed development, aquatic birds and marine mammals. A holistic application of works timing as a mitigation tool is therefore necessary in the context of relative impact severity on a range of receptors, individual species sensitivities, conservation importance and indeed application efficacy of the timing tool for mitigation.

106 The above mitigation suggestions represent the range of possible actions which could be undertaken to reduce noise emissions as well as fish exposure during piling works. Given the precautionary principle mentioned above, it is acknowledged that some mitigation activities might be disproportionate when considering their associated financial costs as well as the uncertainty of the assessment and of the actual effectiveness of the mitigation measures deriving from the lack and high uncertainty of available knowledge. Therefore, it is up to the activity proponent and regulators to evaluate the applicability of proportionate mitigation measures.

107 The monitoring of peak Sound Pressure Levels (SPL) during pile driving operations is usually suggested in order to ensure that the threshold level of harm to fish is not exceeded. However, given the given the paucity of information available for the lamprey species, this type of monitoring should be supported by additional studies aimed at quantifying the hearing ability in lamprey as well as their migrating behaviour within the estuary.

3.2.4. RESIDUAL IMPACTS

108 Residual impacts have been assessed for those operations which produced potentially significant impacts, by incorporating the mitigation measures built into the project design to reduce impacts “at source” as well as those suggested above.

109 The only potentially significant impact on lamprey will arise from noise and vibration emissions during the development construction. It is anticipated that, following effective mitigation, it is likely that there will be a reduction to low levels in the magnitude of the effect. Given that the receptor has been assessed of medium sensitivity, therefore the significance of the residual impact would be minor, hence it is not considered as potentially significant.

3.2.5. CUMULATIVE AND IN-COMBINATION IMPACTS

110 Several other projects in the Humber Estuary have been identified which have the potential to have cumulative or in-combination impacts with the proposed development.

111 Port/harbour facilities in the south bank include the Able UK Northern Area between East Halton Skitter and Chase Hill Road (North Killingholme), the ABP RO-RO Terminal at the Immingham Outer Harbour, the additional berths at the Humber Sea Terminal located at North Killingholme, docks and the ABP RO-RO Berth at Grimsby. Developments along the north bank include the Green Port Hull (formerly known as Quay 2005), and the ABP Hull Riverside Bulk Terminal (HRBT) near the eastern boundary of the Port of Hull. A series of present/future dredging activities connected to these projects occur in the estuary in the vicinity of the proposed AMEP site, such as for example the proposed additional dredging of the Sunk Dredged Channel and Chequer Shoal as part of the proposed deepening of the approaches to Immingham Oil Terminal, the Halton Middle, or the maintenance dredging activities occurring around North Killingholme and Immingham docks areas. These may have cumulative effects with the proposed AMEP project on lamprey migration and on the status of their populations in the Humber Estuary and River Derwent SACs.

112 Cumulative effects would likely arise from impacts due to noise and vibration originating from the increase in vessel traffic and from capital and maintenance dredging, and to habitat disturbance and water quality changes following capital and maintenance dredging.

113 The cumulative effect of noise and vibration on lamprey is likely to be of low magnitude, given that in many cases it would be intermittent and temporary, and also given the avoidance behaviour which could be adopted by lamprey. If considered potentially deleterious, then the impacts would be mitigated when significant, e.g. when a combination of activities might occur, some could be rescheduled. Given that lamprey have been assessed to have a medium sensitivity to noise and vibration (mostly based on a precautionary approach based on the paucity of information on the hearing ability of these species), the cumulative impacts have been assessed as of minor significance. Furthermore, it is unlikely that this impact would act as a barrier to lamprey migration through the estuary, given their ecology as discussed in earlier sections. As such insignificant negative in-combination impacts on the lamprey population status lamprey in SAC areas are expected. The AMEP site will only marginally increase the shipping frequency in the Humber, and as a relatively high background noise is already present due to the large volumes of shipping occurring in the area, lamprey are likely to be habituated to a certain level of background anthropogenic noise and a negligible cumulative impact is assessed as a result of additional vessel traffic.

114 Habitat disturbance, in particular the water quality impairment due to the dredge plumes originating from dredging activities from the AMEP and other developments will have a temporary, discrete and local impact. It is expected that they will be rapidly dispersed to low-background levels in the estuarine environment, considering also the relatively high background turbidity levels occurring in the Humber to which migrating lamprey are likely to be habituated/tolerant. Therefore the resulting cumulative impacts would be of minor significance, and no significant in-combination impacts are expected.

115 The projects identified in the Humber Estuary also include power stations and other industrial plants, such as for example the South Humber Bank Power Station at Stallingborough, the IGC Power Station and the Heron Renewable Energy Plant. Cumulative effects would likely arise from impacts due to the intake of estuarine waters for cooling purposes and the subsequent impingement of fish and other organisms within the

plant. Despite the relatively high impingement rates currently recorded in the Humber from power plant studies, river lamprey populations in the upstream Ouse catchment have been assessed in favourable condition (Nunn *et al.* 2008). However, although the AMEP site is likely to lead to a negligible (very small) increase in lamprey impingement, the resulting cumulative impact with other present and foreseeable projects might be of minor to moderate significance. The resulting lamprey impingement might be a possible threat to the status of the lamprey spp. populations in SAC areas, for example by limiting the number of adults accessing riverine spawning habitats and thus affecting larval recruitment. Therefore, there is the possibility that in-combination impacts of minor to moderate significance may occur, although by necessity, this is a precautionary assessment based on a paucity of evidence regarding population viability in the headwaters of the estuary. The monitoring of fish impingement from the different projects, combined with specific monitoring programs on the estuarine usage by lamprey and on the status of SAC lamprey populations might provide data on the actual cumulative effect on SAC populations, allowing the precautionary findings to be improved in terms of predictive accuracy.

116 Cumulative impacts arising from permanent habitat loss under the footprint of the different project structures are unlikely to be significant, given their relatively low extension compared to the availability of alternative habitats for lamprey in the estuary. The same reasons apply to their potential cumulative impact as physical barriers to lamprey migrations. Therefore the significance of these impacts has been assessed as negligible.

4. SUMMARY OF IMPACT ASSESSMENT

117 This report assesses the possible impacts of the proposed Able Marine Energy Park (AMEP) on river and sea lamprey in the Humber estuary. The status of lamprey receptors has been assessed against the possible effects arising from the construction and operation activities in the proposed development site, based on the available information on the ecology of lamprey species (with particular attention to their estuarine migrating phases) and on the available details of the main physical structures of the development and installation methods. The potential impacts arising from the proposed AMEP development are summarised in Table 2.

Table 2. Impact Assessment Summary

Project phase	Impact source	Magnitude of Effect	Sensitivity of Receptor	Significance	Possible Mitigation	Significance after Mitigation	Cumulative / In-combination impacts
Constr.	Noise and vibration	Low to possibly Medium	Medium	Minor to possibly Moderate	Technical measures (e.g. soft-start, flap anchors etc.)	Minor	Minor
	Water abstraction	Low	High	Minor	--	--	Minor to possibly moderate
	Habitat disturbance	Low	Medium	Minor	--	--	Minor
	Permanent habitat loss	Low	Medium	Minor	--	--	Minor
Operat.	Noise and vibration	Negligible	Medium	Negligible	--	--	Negligible
	Habitat disturbance	Negligible	Medium	Negligible	--	--	Minor
	Physical barrier to migration	Negligible to Low	High	Negligible to Minor	--	--	Negligible

118 Noise and vibration generated during construction works (mainly from piling) are likely to have the greatest impacts on lamprey during their estuarine migratory phases, potentially leading to injuries, mortalities and behavioural effects. A summary of the lines of evidence taken into account (considering their level of uncertainty) and the derived conclusions is provided in Table 3. Based on these conclusions, it has been necessary to adopt a precautionary approach. The overall assessment of construction noise impacts on lamprey is considered to be of minor to possibly moderate significance. This impact may be mitigated to possibly non significant levels by undertaking appropriate and proportionate measures to reduce the noise pressure and the duration or timing of impact, the evaluation of their applicability being up to the activity proponent and regulators. It is of note that, given the uncertainties associated with hearing ability of lamprey, also the benefits of mitigation will be uncertain.

Table 3. Summary of lines of evidence, level of uncertainty and the derived conclusions taken into account for the assessment of impact arising from piling noise.

Lines of evidence				
Reasonably Certain		**Likely**		**Uncertain**
Sufficient scientific evidence or understanding exists, with a reasonable degree of concordance between authorities, that statements can be made with reasonable certainty		Some evidence exists, but some may be conflicting, or evidence is insufficient so that reasonable certainty is not attained		Evidence is absent, or evidence is so conflicting that no clear indication can be discerned
Piling will generate underwater noise and vibration	⇨	Sound will be above ambient levels over the width of the estuary	⇨	Whether or not lamprey can perceive sound or vibration
Fish in the immediate vicinity of loud underwater noises can suffer mortality	⇨	⇨	⇨	Whether fish in the immediate vicinity of underwater piling will suffer mortality
	⇨	⇨	⇨	How/whether previous piling campaigns have impacted on fish ecology in the Humber
Mortality is not generally observed in the vicinity of marine driven piling works	⇨	⇨	⇨	Whether any physical effects are experienced by the lamprey
Behavioural responses to noise occur in some fish	⇨	⇨	⇨	Whether any behavioural response exhibited by lamprey
		That lamprey will use the whole width of the estuary	⇨	Whether a deterrent effect of noise will disrupt lamprey migration
		That lamprey have a reduced swimming capacity	⇨	Whether avoidance behaviour (if occurring) can significantly reduce the duration of exposure to noise impact
		That the population of river lamprey is present in the estuary in moderate abundance		
		That the population of sea lamprey is present in the estuary in low abundance		
		That river lamprey will occur in the estuary as young individuals from May to August (downstream migration) and as adult individuals from July to January (spawning upstream migration)		That sea lamprey will occur in the estuary as young individuals from July to October (downstream migration) and as adult individuals from April to June (spawning upstream migration)
Piling noise values at 25m from source are: RMS = 197dB re 1μPa, Peak = 212 dB re 1μPa, SEL = 188dB re 1μPa^2 s (Single strike, worst case scenario)	⇨	Under a scenario of 7000 strikes/day the area where the noise pressure will be attenuated to the injury threshold will extend to the whole width of the estuary (7.3km from the piling noise)	⇨	Whether noise levels are applicable to lamprey
Underwater noise attenuation varies with the sound frequency and physical properties of the environment	⇨	A high uncertainty is present for prediction of attenuation area extending farther than 1km from the noise source	⇨	Whether noise levels are applicable to lamprey
Conclusions				
There is a weight of scientific opinion that some fish will avoid areas where underwater noise is elevated.				
There is no scientific certainty that lamprey can hear or that they cannot and therefore whether or not they would avoid swimming in proximity to marine piling works.				
There is no scientific evidence to support either the assertion that underwater noise can have an adverse effect on lamprey populations or the alternative assertion that it does not.				
There is high scientific uncertainty about the consequences or likelihood of the impact.				

119 Other potential impacts on lamprey during construction may arise following fish impingement due to water abstraction during hydraulic dredging and rainbowing activities, as well as from sediment re-suspension, water quality changes, and subtidal habitat loss due to capital dredging. However, these impacts have been assessed as of minor significance due to their effect being highly localised and temporary.

120 Potential impacts on lamprey during the operational phase mainly arise from underwater noise generated by the increased vessel traffic and maintenance dredging, sediment re-suspension and water quality changes due to this latter activity and to run-off from the quay or vessels. However these impacts are considered to be negligible, due to the generally low disturbance intensity and temporary effect. A further impact could arise from the physical presence of the quay structure which might constitute a barrier to lamprey migration. However this impact has been assessed as of negligible to minor significance, given the limited extension of the quay structure compared to the overall subtidal habitat available for lamprey migration.

121 Several other projects in the Humber Estuary have been identified which have the potential to have cumulative or in-combination impacts with the proposed development, including port/harbour facilities along the estuarine banks and present/future dredging activities connected to these projects. Cumulative effects would likely arise from impacts due to noise and vibration originating from the increase in vessel traffic and from capital and maintenance dredging, to habitat disturbance and water quality changes following capital and maintenance dredging, However such cumulative and in-combination impacts on lamprey have been assessed as of minor significance, given that these impacts would be temporary, discrete and local, relatively high background levels are already present in the estuary (e.g. for shipping noise and suspended sediment concentrations), and assuming that the impacts would be mitigated when significant. There is the possibility that in-combination impacts of minor to moderate significance may occur, arising from the high fish impingement levels following the intake of estuarine waters for cooling purposes at the power stations and other industrial plants in the Humber Estuary. However, this is a precautionary assessment based on a paucity of evidence regarding population viability in the headwaters of the estuary. The monitoring of fish impingement from the different projects, combined with specific monitoring programs on the estuarine usage by lamprey and on the status of SAC lamprey populations might provide data on the actual cumulative effect on SAC populations, allowing the precautionary findings to be improved in terms of predictive accuracy.

5. REFERENCES

Abou-Seedo FS, Potter IC, 1979. The estuarine phase in the spawning run of the river lamprey *Lampetra fluviatilis*. *Journal of Zoology*, 188, 5-25.

Beamish FWH, 1980. Biology of the North American anadromous sea lamprey, *Petromyzon marinus*. *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 1924-1943.

Buckland F, 1878. *Salmon Fishery Report*. Her Majesty's Stationery Office: London.

Burdon D, Mazik K, Perez-Dominguez R, 2010. *South Humber Channel Marine Studies: Intertidal and Subtidal Benthic & Fish Surveys 2010*. Institute of Estuarine and Coastal Studies, University of Hull.

California Department of Transportation, 2009. *Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish*. Final Report.

COE, 1979. *Convention on the Conservation of European Wildlife and Natural Habitats*. Council of Europe. Treaty 104.

COM, 2000. *Communication from the Commission on the precautionary principle. Commission of the European Communities*. Brussels, 2.2.2000. COM(2000) 1 final.

Davies CE, Harding PT, Arnold HR, 2002. *Database and atlas of freshwater fishes in the UK: Final report*. ISBN 1 85705 923 9.

Dawes OJ, 2007. *The monitoring of lamprey impingement at Elvington. A raw water intake and treatment facility on the lower Yorkshire Derwent, a three year report*. Institute of Estuarine and Coastal Studies, University of Hull.

Dodson JJ, Leggett WC, Jones RA, 1972. The behaviour of adult American shad (*Alosa sapidissima*) during migration from salt to fresh water as observed by ultrasonic tracking techniques. *Journal of the Fisheries Research Board of Canada*, 29, 1445-1449.

EC, 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Official Journal of the European Communities* L206/35, 22 7 92, 7-50.

English Nature, 2001. *Habitats regulations guidance note - Alone or in combination*. HRGN No. 4.

English Nature, 2003. *The Humber Estuary: a comprehensive review of its nature conservation interest*. English Nature Research Reports. Report No. 547.

Farmer GJ, 1980. Biology and physiology of feeding in adult lamprey. *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 1751-1761.

Grabarkiewicz JD, Davis WS, 2008. *An introduction to freshwater fishes as biological indicators*. EPA-260-R-08-016. U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC.

Götz T. Hastie G, Hatch LT, Raustein O, Southall BL, Tasker M, Thomsen F, 2009. *Overview of the impacts of anthropogenic underwater sound in the marine environment*. OSPAR Commission Report no. 441/2009.

Hardisty MW, 1961. The growth of larval lampreys. *Journal of Animal Ecology*, 30, 357-371.

Hardisty MW, 1986a. *Lampetra fluviatilis.* In: *The freshwater fishes of Europe*, Volume 1, Part I Petromyzontiformes. Ed. Juraj Holcik. Wiesbaden. Aula-Verlag. pp 249-278.

Hardisty MW, 1986b. *Lampetra fluviatilis.* In: *The freshwater fishes of Europe*, Volume 1, Part I Petromyzontiformes. Ed. Juraj Holcik. Wiesbaden. Aula-Verlag. pp 98 - 116.

Hardisty MW, 2006. *Lampreys. Life without jaws*. Forrest Text, UK.

Hardisty MW, Potter IC, 1971. *The Biology of Lampreys*, Volume 1. Academic Press, London.

Harvey JP, Nunn AD, Cowx IG, 2006. *Survey of larval lamprey (ammocoetes and transformers) in the Yorkshire Ouse and Derwent catchments, 2004*. Report to Environment Agency.

Harvey JP, Cowx IG, 2003. *Monitoring the river, brook and sea lamprey*. Conserving Natura 2000 Rivers Monitoring Series no. 5, English Nature, Peterborough.

Hasler AD, Gardella ES, Horrall RM, Henderson HF, 1969. Open water orientation of white bass, *Roccus chrysops*, as determined by ultrasonic tracking methods. *Journal of the Fisheries Research Board of Canada*, 26, 2113-2192.

Hemingway KL, Cutts ND, Allen JH, Thomson S, 2008. *Habitat Status of the Humber Estuary, UK*. Institute of Estuarine & Coastal Studies (IECS), University of Hull, UK. Report produced as part of the European Interreg IIIB HARBASINS project.

Hill AE, 1995. The kinematical principles governing horizontal transport induced by vertical migration in tidal flows. J*ournal of the Marine Biological Association of the United Kingdom*, 75, 3-13.

Hiscock K, Tyler-Walters H, Jones H, 2002. *High level environmental screening study for offshore wind farm developments – Marine Habitats and Species Project*. Report from the Marine Biological Association to The Department of Trade and Industry New & Renewable Energy Programme. AEA Technology, Environment Contract: W/35/00632/00/00.

IECS, 2000. *Fish impingement assessment at South Humber Bank Power Station year 1*. Institute of Estuarine and Coastal Studies, University of Hull.

IEEM, 2010. *Guidelines for ecological impact assessment in the United Kingdom*. Final document.

Igoe F, Quigley DTG, Marnell F, Meskell E, O'Connor W, Byrne C, 2004. The sea lamprey *Petromyzon marinus* (L.), River Lamprey *Lampetra fluviatilis* (L.) and Brook lamprey *Lampetra planeri* (Bloch) in Ireland: General biology, ecology, distribution and status with recommendations for conservation. *Biology and Environment: Proceedings of the Royal Irish Academy*, 104B, 43-56.

Jabusch T, Melwani A, Ridolfi K, Connor M, 2008. *Effects of short-term water quality impacts due to dredging and disposal on sensitive fish species in the San Francisco Bay*. San Francisco, CA: San Francisco Estuary Institute.

Jang MH, Lucas MC, 2005. Reproductive ecology of the river lamprey. *Journal of Fish Biology*, 66, 499-512.

Kelly FL, King JJ, 2001. A review of the ecology and distribution of three lamprey species, *Lampetra fluviatilis* (L.), *Lampetra planeri* (Bloch) and *Petromyzon marinus* (L.): a context for conservation and biodiversity considerations in Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy*, 101B, 165-185.

Larsen LO, 1980. Physiology of adult lampreys, with regard to natural starvation, reproduction and death after spawning. *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 1762-1779.

Law BS, Dickman CR, 1998. The use of habitat mosaics by terrestrial vertebrate fauna: implications for conservation and management. *Biodiversity and Conservation*, 7, 323–333.

Leaf J, 1908–1914. *Naburn, fishing accounts*. Unpublished financial accounts logbook of the Naburn Fishery, held at Environment Agency, York, UK (available through P.A. Frear).

Leighton A., 2008. *Assessment of lamprey impingement at South Humber Bank Power Station: November 2003 - February 2006*. Institute of Estuarine and Coastal Studies, University of Hull.

Lenhardt ML, Sismour E, 1995. Hearing in the sea lamprey (*Petromyzon marinus*) and the long nose gar (*Lepisosteus spatula*). *The Association for Research in Otolaryngology*, Abstract: 259.

Lucas MC, Mercer T, Batley E, Frear PA, Peirson G, Duncan A, Kubecka J, 1998. Spatio-temporal variations in the distribution and abundance of fish in the Yorkshire Ouse system. *The Science of the Total Environment*, 210–211, 437–455.

Lucas MC, Bubb DH, Jang M-H, Ha K, Masters JEG, 2009. Availability of and access to critical habitats in regulated rivers: effects of low-head barriers on threatened lampreys. *Freshwater Biology*, 54, 621-634.

Maes J, Peeters B, Ollevier F., Parmentier A, Thoelen E, Franchois H, Turnpenny AWH, Lambert DR, Nedwell JR, 1999. *Evaluation of the fish guidance system at the cooling water inlet of the Nuclear Power Plant Doel 3/4*. Studierapport in opdracht van Electabel NV, Kerncentrale Doel. Katholieke Universiteit Leuven, Department Biology, Laboratory of Aquatic Ecology.

Maes J, Turnpenny AWH, Lambert DR, Nedwell JR, Parmentier A, Ollevier F, 2004. Field evaluation of a sound system to reduce estuarine fish intake rates at a power plant cooling water inlet. *Journal of Fish Biology*, 64, 938-946.

Maitland PS, 1980. Scarring of whitefish (*Coregonus lavaretus*) by European river lamprey (*Lampetra fluviatilis*) in Loch Lomond, Scotland. *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 1981-1988.

Maitland PS, Morris KH, East K, Schoonoord MP, Van Der Wall B, Potter IC, 1984. The estuarine biology of the river lamprey, *Lampetra fluviatilis*, in the Firth of Forth, Scotland, with particular reference to size composition and feeding. *Journal of Zoology*, 203, 211-225.

Maitland PS, Campbell RN, 1992. *Freshwater fishes*. London Harper and Collins.

Mallatt J, 1981. The suspension feeding mechanism of the larval lamprey *Petromyzon marinus*. *Journal of Zoology*, 194, 103-142.

Marshall S, Elliott M, 1998. Environmental influences on the fish assemblage of the Humber estuary, U.K. *Estuarine Coastal and Shelf Science*, 46, 175-184.

Masters JEG, Jang MH, Ha K, Bird PD, Frear PA, Lucas MC, 2006. The commercial exploitation of a protected anadromous species, the river lamprey (*Lampetra fluviatilis* (L.)), in the tidal River Ouse, north-east England. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 16, 77-92.

McCleave JD, Horrall RM, 1970. Ultrasonic tracking of homing cutthroat trout (*Salmo clarki*) in Yellowstone Lake. *Journal of the Fisheries Research Board of Canada*, 27, 715-730.

McCleave J, Artnold GP, Dodson J, Neill WH, 1984. *Mechanisms of migration in fishes.* Plenum Press, New York.

Natural England, 2009. *Conservation objectives and definitions of favourable condition for designated features of interest. Humber Estuary SSSI*. Draft version, December 2009.

Nedwell L, Langworthy J, Howell D, 2003. *Assessment of sub-sea acoustic noise and vibrations from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore windfarms, and comparison with background noise*. COWRIE report no. 544 R 0424, 2003.

Nedwell JR, Parvin SJ, Edwards B, Workman R, Brooker AG, Kynoch JE, 2007. *Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters*. Subacoustech Report No. 544R0738 to COWRIE Ltd. ISBN: 978-0-9554279-5-4.

Nedwell JR, Brooker AG, Barham RJ, 2011. *Subsea noise modelling in support of the European Offshore Wind Deployment Centre Development*. Subacoustech Environmental Report No. E278R0215.

Nunn AD, Harvey JP, Noble RAA, Cowx IG, 2008. Condition assessment of lamprey populations in the Yorkshire Ouse catchment, north-east England, and the potential influence of physical migration barriers. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 18, 175-189.

OSPAR, 2008. *Assessment of the environmental impact of offshore wind-farms*. Biological Diversity and Ecosystems Series. Publication no. 385/2008.

Perez-Dominguez R, 2008. *Fish Pilot Studies in the Humber Estuary, UK*. Institute of Estuarine and Coastal Studies, University of Hull, UK. Report produced as part of the European Interreg IIIB HARBASINS project.

Phillips R, Rix M, 1985. *A guide to the freshwater fish of Britain, Ireland and Europe*. London Treasure Press.

Packard A, Karlsen HE, Sand O, 1990. Low frequency hearing in cephalopods. *Journal of Comparative Physiology A*., 166, 501 - 505.

Pickering AD, 1993. *Physiological aspects of the life cycle of the river lamprey,* Lampetra fluviatilis *L*. Freshwater Biological Association Annual Report, 46, 41-47.

Poddubny AG, 1961. *Sonic tags and floats as a means of studying fish response to natural environmental changes and to fishing gear*. FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics. Bergen, Norway, Exper. Pap., 46, 1-8.

Popper AN, 2005. *A review of hearing by sturgeon and lamprey*. Report to the U.S. Army Corps of Engineers, Portland District.

Popper AN, Hastings MC, 2009. The effects of human-generated sound on fish. *Integrative Zoology*, 4, 43-52.

Potter IC, 1980a. The petromyzontiformes with particular reference to paired species. *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 1595-1615.

Potter IC, 1980b. Ecology of larval metamorphosing lampreys. *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 1641-1657.

Potter IC, Huggins RJ, 1973. Observations on the morphology, behaviour and salinity tolerance of downstream migrating river lampreys (*Lampetra fluviatilis*). *Journal of Zoology*, 169, 365-379.

Proctor N, Musk W, 2001. *Fish impingement assessment at South Humber Bank Power Station, final report; year 2*. Institute of Estuarine and Coastal Studies, University of Hull.

Quintella BR, Póvoa I, Almeida PR, 2009. Swimming behaviour of upriver migrating sea lamprey assessed by electromyogram telemetry. *Journal of Applied Ichthyology*, 25, 46-54.

Smith S, 1912. *Snowden Slights, Wildfowler*. T.A.J. Waddington: York.

Spicer JI, 1937. *The ecology of the River Trent and its tributaries*. Handbook of the British Association for the Advancement of Science 1937: 3–8.

Yuen HSH, 1970. Behaviour of skipjack tuna, *Katsuwonus pelamis*, as determined by tracking with ultrasonic devices. *Journal of the Fisheries Research Board of Canada*, 27, 2071-2079.

Wheeler A, 1969. *The Fishes of the British Isles and North West Europe*. MacMillan.

Whitton BA, Lucas MC, 1997. Biology of the Humber rivers. *The Science of the Total Environment*, 194–195, 247–262.

Wilcox BA, Murphy D, 1985. Conservation strategy: the effect of fragmentation on extinction. *American Naturalist*, 125, 879–889.

William F, Beamish H, 1979. Migration and spawning energetics of the anadromous sea lamprey, *Petromyzon marinus*. *Environmental Biology of Fishes*, 4, 3-7.

Windward Environmental LLC, 2009. *Baseline ecological risk assessment evaluation of lamprey sensitivity to sediment contaminants*. Portland Harbor RI/FS Draft Remedial Investigation Report.