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Science Advisory Report No 006

Methodology for the measurement of impingement

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Executive summary

This report is one of a series that examines the methods and methodologies used and/or required for examining the effects of power stations, specifically new nuclear build (NNB), on the marine environment in terms of regulatory compliance. This report deals with Impingement.

Definitions and context are provided, as is a commentary on the methods and results.

Methods are described for base-data collection and supplementary field studies to provide the necessary information on the diversity and abundance of the species impinged.

The use of the outputs is examined to ensure the conclusions are scientifically valid in terms of significance with respect to station operation and ecological and social issues.

There is no universal technique that will provide a comprehensive understanding of impingement at all sites and under all conditions. However, this report critically reviews a wide range of techniques and methods, which will allow a suitable monitoring and assessment programme to be designed for all potential NNB sites.

This sequence of component methods, identified as a methodology for measuring impingement, adds to the UK suite of methods and methodologies as well as providing a formalised approach to the specifics of estimating the effects of direct-cooled power stations on the biota in the marine environment.

1 Introduction

Since the last cycle of NNB in the UK, there have been many developments in techniques, technology, understanding of ecology, and legislation. These include the adoption of the Ecosystem Approach, the introduction of new, primarily EU-led, legislation and increases in public and regulatory expectations (all within a background of climate change).

The large volumes of cooling water (CW) abstracted by direct-cool power stations inevitably captures quantities of marine fauna and flora which subsequently impinges on the intake screens. Good design can both reduce the quantity of material captured and ensure maximum survival and subsequent return to the marine environment of organisms impinged. Material passing through the intake screens and entering the condensers is described as ‘entrained’ and is considered in BEEMS Science Advisory Report No 005

We consider a methodology to be a combination and sequence of methods (see Appendix A for definitions). This report covers methods for measurement and modelling, as well as potential resources for relevant data.

This series of reports results from a workshop held by the Expert Panel on methodologies. The workshop adopted a *who, what, why, where, when and how?* approach which is partially retained in the reports. It also used argument-mapping to clarify ideas and relationships.

This series of Scientific Advisory Reports reflects the current state of knowledge. They will be revised as further information becomes available.

2 Why: definition, importance, data, context

2.1 Definition

Impingement is the retention of organisms on power station CW intake screens.

2.2 Importance

Impingement is important because the organisms may be removed from the ecosystem, or may be returned to the source water body in a weakened condition, injured or dead. It is often a highly visible impact for power station visitors, sometimes attracting adverse publicity, and therefore damaging the company's environmental reputation. It may also represent a health and safety hazard. The impinged organisms may be returned to the source waters, and are thus seen as dead or injured organisms washed up adjacent to the intakes, or disposed of to landfill. In essence, impingement has to be determined (and thus communicated to the operators) as (a) the effect of the intakes on the local marine ecology, and (b) the effect of the local marine ecology on the power plant operation.

2.3 Data: biological resources and predicted impact

During the operation of power stations, fish, mobile invertebrates (eg, jellyfish, copepods, mysids) and drifting algae, including eggs and larval stages present in the CW source body, will inevitably be drawn in with the CW supply. Depending on the size of the band or drum screen meshes (often 1 cm^2), fish that are too large to pass through will become impinged on the screens, while smaller individuals, including the egg and larval phases, will be entrained into the cooling circuit and returned (live or dead) to the wild (see BEEMS Science Advisory Report No 005 on entrainment). Where screens are fitted with fish recovery and return (FRR) technology – a requirement under current Environment Agency Best Practice Guidance in England and Wales (O'Keefe and Turnpenny, 2005) – organisms will be returned to the wild in varying condition. Whether their discharge to sea should be treated as a trade waste differs according to proposed practice. The Environment Agency has no formal policy, but Turnpenny *et al.*, (2010) give the following guidance:

- if the waste is returned to the water in a continuous stream, along with entrained material, there should be no consenting issues. This reduces landfill waste.
- maceration of screen arising may be acceptable if discharged continuously. A degree of maceration occurs incidentally on some current, more primitive, fish return systems.
- concentrated dumping of accumulated waste would be a different matter and could have significant waste and water quality issues.

On the last point, the operating consent for the Sizewell B Power Station fish return system required a means of monitoring fish throughput in the return system (visual observation/CCTV camera) so that the fish return launders could be diverted into trash baskets if abnormally high numbers of fish were being returned to sea.

Over the past 30 years or so, power station screen surveys have been carried out at most coastal power stations to obtain data on impingement rates. In some cases, the surveys have been designed to give unbiased estimates of annual impingement rates, from which the significance of impacts can be assessed. In other cases, data have been collected for other purposes, for example to monitor temporal changes in populations, and may be biased diurnally or towards certain tidal conditions. This would mean that fully quantitative annual assessments could not be derived from the available data.

Quantities of fish impinged annually reported for coastal power stations ranges from less than 1 tonne y^{-1} at smaller stations or those fitted with fish protection technologies, to tens or even hundreds of tonnes per year. As well as fish, large quantities of crustaceans (swimming crabs, lobster and shrimp), molluscs such as cuttlefish, squid and octopus, jellyfish and seaweed are often retained by CW screens. The type of organisms taken from the source water area is dependent on the position of the intakes (in the surface, middle, lower or within the bed) and the type, mobility and swimming behaviour of the organisms.

Prior to the 1980s, impinged organisms were, at all but a few sites, put to waste as landfill. During the planning of Sizewell B Power Station, it was argued by the environmental team that putting impinged material back to sea in whatever condition would at least return them as organic matter to the marine food chain. The Sizewell B Power Station operating consents were successfully negotiated to include this option.

At some newer Combined Cycle Gas Turbine (CCGT) stations (eg, Barking, Great Yarmouth, Shoreham and Marchwood) more refined FRR systems allow at least the more robust organisms to be returned to the source water unharmed. FRR systems are more cost-effective when implemented from the design phase, although at Stallingborough CCGT, the FRR was fitted retrospectively. The ecological impacts are then confined to smaller residual impacts on the less robust organisms. Thus good CW intake design and, where appropriate, use of fish deflection technologies at the point of water inlet (eg, acoustic deterrents, strobe lights and bubble curtains) combine to reduce effects.

As well as impingement losses potentially affecting the local ecology, occasional massive influxes of organisms can have an impact upon station operation. A number of UK and French coastal stations have suffered damage to screening systems or have lost efficiency, been forced to shut down or reduce generation, following inundations of sprat shoals, seaweed or jellyfish.

These episodic events are frequently seasonal and associated with natural biological and climatic cycles. For example, onshore breeding migration of lumpsucker fish led to regular annual mortalities of males and gravid females at Torness Power Station.

2.4 Context

2.4.1 What is the financial cost to the power station?

Where impinged organisms and debris are not returned to the water body, ongoing costs arise from landfill disposal because the material is treated as a potentially polluting, organic waste. Additional *ad hoc* costs, often amounting to millions of pounds sterling per event, can arise from the loss of generation and the costs of labour to clear blockages or carry out repairs following biological inundation events.

2.4.2 What are the health and safety issues for the power station?

The temporary storage on site of biological waste from impingement catches may create a biohazard and odour nuisance, especially during warmer summer months. It also encourages predators and scavengers on site, including seabirds, foxes and vermin.

At one site in Scotland where fish impingement levels are particularly high, the health and safety hazard includes the accumulation of deep deposits of wet seabird excrement on the intake jetty. Hawks are regularly employed to scare seabirds away. At another site, workers were found removing the edible sized fishes, especially cod and whiting, such that the operator had to erect notices forbidding this.

2.4.3 Are there issues regarding the aesthetics and perception of the impingement?

Impingement is an unwanted and undesirable side effect of power generation, and operators would prefer it not to happen. While numerous scientific studies have demonstrated that quantities involved are not necessarily of significance when compared to other factors, the public perception is generally less forgiving. South Humber Bank Power Station (Stallingborough CCGT) was some years ago subjected to a campaign of media attack, for example, when visitors to the site noticed apparently large quantities of commercial-sized fish accumulating in skips on site – indeed some power stations have been described as 'stationary trawlers'. At another (nuclear) site, the use of an FRR system was of concern as this was likely to result in dead fish washing up on nearby beaches and hence leading the public to regard this as an effect of the nuclear aspect of operation rather than the CW intake.

2.4.4 Commercial sizes and species

CW intakes are not discriminating about the species of organisms impinged: if they are in the vicinity of the intake, they are at risk, although size and stratification may affect their susceptibility. However, the species composition impinged is biased towards the material occurring at the particular depth from which the water is withdrawn (hence taking surface, midwater, pelagic or benthic species). The most common species impinged are generally the most abundant in the locality. Pelagic fish often dominate the catch, especially at open coastal sites, again, depending on the position of the intakes.

Despite the above situation at Stallingborough, most impinged fish tend to be small, typically less than 20 cm in length. Again, this reflects the predominance of younger age classes in stocks and an estuarine and inshore situation, but it also reflects a degree of size-selectivity caused by the interaction between fish swimming ability and intake current velocity, whereby larger fish have a better chance of escape.

Commercial fishermen are usually the first to object to impingement losses of commercial species. The common commercial species affected include cod (*Gadus morhua*), whiting (*Merlangius merlangus*), plaice (*Pleuronectes platessa*), dab (*Limanda limanda*), herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). Although most of the impinged fish would be below the statutory minimum commercial landing size, the fishing industry itself is prevented from landing these undersized fish in order to protect the stocks' future. Thus the industry considers it unacceptable for power stations to take them.

2.4.5 Disturbance to the ecology

Ecological impacts may arise where removal of organisms from a stock or community by impingement is sufficient to affect the population dynamics or community structure. This is most likely where the CW intake is located within a critical area of habitat where a high proportion of the population is, at some point in the life-cycle, concentrated; examples include:

- near to a discrete spawning/nursery area (eg, for herring on nearby gravel seabed, lumpsucker on nearby rocky shores);
- with large resident estuarine population (eg, cucumber smelt (*Osmerus eperlanus*), brown shrimp (*Crangon crangon*));
- on a migration route (especially diadromous species such as salmon (*Salmo salar*), Twaite shad (*Alosa fallax*), lamprey (*Petromyzon marinus; Lampetra fluviatilis*), eel (*Anguilla anguilla*));
- a discrete local population of an inshore species (eg, sand smelt, *Atherina presbyter*).

It could also occur within more widespread populations through the combined impingement impacts of numerous power stations acting upon the same stock.

2.4.6 Conservation importance and regulatory context

Species noted as being of conservation importance most vulnerable to impingement include all the diadromous species listed in previous sections. The importance of a species or community at any given site will depend on local conservation designations and conservation objectives (eg, Natura 2000 sites), hence the operation (regarded as a 'Plan or Project' under the EC Habitats Directive[1]) is subject to an Appropriate Assessment. Similarly, the plant would be regarded as an anthropogenic pressure under the EC Water Framework Directive or the EC Marine Strategy Framework Directive (depending on its situation), which would affect the ability of the area to reach Good Ecological Status or Good Environmental Status respectively.

Secondly, despite the material being taken from the adjacent area and merely being biological material, the return of the impinged material to the source water area either via the CW outlet or by disposal from a vessel may require licensing as an organic (and hence potentially polluting) discharge under the Control of Pollution Act (and its successors) or Food and Environmental Protection Act as applicable (but see section 3.1.3, paragraph 1).

[1] Council Directive (92/43/EEC) on the conservation of natural habitats and of wild fauna and flora (Habitats Directive) [amended 2006/105/EC]

3 How: methods and results

3.1 Methods

3.1.1 Introduction

The methods indicated below describe a number of approaches for obtaining data on the quantities of fish that are likely to be impinged at a new build power station, and also on local sensitivities with regard to commercial fishing, local ecological issues and designations.

3.1.2 Consult local fisheries managers, conservation bodies and scientists

Consultation with local stakeholders and interest groups or individuals is a useful first step in gauging and prioritising likely issues (sensitivities), as well as in identifying species that are likely to be at risk or a threat to operations.

Potential consultees in this group would include, for example:

- the Inshore Fisheries and Conservation Authorities (IFCAs) as successors to the Sea Fisheries Committees
- the Marine Management Organisation
- specialists within UK environment protection and conservation agencies and other statutory bodies (Environment Agency, Scottish Environmental Protection Agency, Northern Ireland Environment Agency, Natural England, Countryside Council for Wales or Scottish Natural Heritage)
- Cefas fishery scientists
- the Marine Biological Association (MBA) based in Plymouth
- biodiversity data centres (based regionally) and marine recorders at natural history museums
- other marine laboratories, university groups and environmental consultants known to have worked in the area

3.1.3 Consult published data

Published data in this context should be taken in the broadest sense. Sources might include:

- papers in scientific journals and proceedings
- books
- 'grey' literature, including ICES[2] reports consultancy reports and PhD theses
- publicly accessible databases, such as United Kingdom Digital Marine Atlas (UKDMAP)[3] and Fisheries Sensitivity Maps in British Waters[4]

[2] International Council for the Exploration of the Sea
[3] http://www.bodc.ac.uk/products/bodc_products/ukdmap (accessed 15.02.11)
[4] http://www.cefas.co.uk/media/29947/sensi_maps.pdf (accessed 15.02.11)

3.1.4 Carry out sampling to fill gaps

Vessel-based field sampling

Once all relevant and accessible data have been obtained by desk study, it is likely that there will be a need to update and consolidate data by undertaking baseline field surveys. Such surveys should be carried out primarily within the abstraction 'footprint' of the proposed station, and at comparable undisturbed reference sites that will be used post-commissioning for assessing whether any observed changes can reasonably be attributed to station operation.

The size of the abstraction footprint will vary from site to site, being strongly influenced by the length of the tidal excursion, but it will also be influenced laterally by the mobility of the species concerned. As a rule of thumb, it will be an elongated strip running longshore, roughly along the depth contour of the intake and in length may be taken as ± the tidal excursion from the intake centre, and perhaps 100 m to either side. In many cases the sampling area may be conveniently delimited by local geography, eg, within a bay in which the intake is located. It is of note that in many macrotidal areas around the UK, and especially in macrotidal estuaries, the tidal excursion can be 15–20 km.

Finding suitable reference sites can be problematical. The need is to find an area similar in size to the abstraction footprint and with comparable habitat characteristics (depths, substratum, macrovegetation type and extent and exposure). For example, at Fawley Power Station (Hampshire), which abstracts from an east-facing dredged tidal creek, the adjacent and parallel Ashlett Creek is used as one of the reference sites; another with similar characteristics is located further away on the Isle of Wight. Another example, Shoreham Power Station (West Sussex) uses Worthing Bay for reference. These comparisons are never perfect and care should be taken to identify what habitat characteristics are most relevant for the species in question. Similarity analyses using multivariate software packages such as PRIMER or BROGDAR may be helpful (Henderson (2003) and Elliott & Hemingway (2002) describe the field and laboratory methods for collecting and analysing the data).

Sampling techniques should be compliant with Water Framework Directive (WFD) methodologies. For fish, multi-method sampling should always be used in order to avoid inherent selectivities of different gear types. Common techniques employed include trawling using otter, bass or beam trawls, and for shallow areas, seine netting, fyke netting and push netting. The most important issue is to use a range of techniques best suited to the locality but with emphasis on sampling the water column or bed component that approximates most to the position of the intakes; for example expending a large effort to sample pelagic populations when the proposed intake will be either demersal or benthic may not give the most accurate indication of potential impingement.

Site-based field sampling

Where there is an existing power station still operating on or close to a proposed NNB site, there may be an opportunity to conduct impingement sampling. This may be desirable even where previous impingement survey data for the site exist, for a number of possible reasons:

- existing data do not provide an unbiased sample with respect to tidal, diurnal and seasonal factors
- data not available for a full year
- data may be out-of-date (ie, not representative of current state of stocks)
- methods for field based sampling are detailed in Appendix B

3.1.5 Consult existing local power station data, if available

The best guide to likely impingement rates at a new station will be historical impingement data for older power stations on the same site or in the locality. Many older stations have been surveyed at some time in the past and newer stations built within the last 10 years have generally been required to conduct post-commissioning surveys for three years or more from start-up.

Care should be exercised when using existing data in a quantitative way to ensure that it is free from sampling bias. Often, data will have been collected for a different purpose and may not be a reliable indicator of annual rate. It may be because the data have not been collected over a full year, are daytime samples only (night-time catches may be higher at some sites) or have been collected only at certain tidal states. Nonetheless, such data will provide a very useful indication of species and lifestages at risk and any seasonal occurrence in that area.

A further 'health-warning' on historical data: impinged catches may be dominated at some sites by one or two key species, often pelagic. These can vary substantially in abundance between years. Turnpenny and Taylor (2000) describe a standardisation procedure for commercially-exploited species that can be used to reduce bias from this source. For non-commercial species, scientific literature may offer some indication of likely interannual fluctuations.

3.1.6 Apply PISCES

PISCES (Prediction of Inshore Saline Communities Expert System) is expert system software developed to predict order of magnitude impingement catches at sites for which no pre-existing survey data are available. It is based on some 20 years of research into impingement rates at coastal power stations, which has allowed the development of ecological rule-sets that enable predictions pertaining to 'greenfield' sites. PISCES was developed using data from British and northern European (Dutch and French) power stations, and has recently been updated under the BEEMS programme. Consequently, its predictions are most accurate for geographical areas that provided data for deriving and calibrating the software; also, the model is often more accurate for predicting species richness and composition, which by their nature are dependent on the receiving habitat type. The prediction of abundances is often less satisfactory given that these are dependent on stochastic and biologically dependent processes (eg, the catch of 0+ fish being dependent on the strength of recruitment in relation to the size of local predator populations in any one year).

Outputs from PISCES include:

- predicted annual catch rates per unit of CW abstraction flow for around 32 common marine and estuarine species and common crustaceans
- predicted seasonality of impingement
- conversion of catch rates for a number of commercial species into Equivalent Adult Values (EAVs)

3.2 Results

Using a combination of some or all of the above sources, the aim should be to compile a data-set that will yield the following information required for Environmental Impact Assessment, Appropriate Assessments and for station operational risk assessment:

- a list of the 20 or so more common fish and invertebrate species in the locality that are likely to make up the bulk of the impingement catch (generally the top ten species constitute >80% of the catch)
- predictions of their annual impingement rates (± coefficient of variation if possible)
- the lifestages at risk, or of threat to station operation
- their seasonality
- cumulative impacts on the same stocks from other power stations and large industrial projects (eg, refineries, desalination plants)
- importance of species to local, regional, national and international fisheries that may be affected (including landings data)

- local fisheries concerns among commercial fishermen and recreational anglers
- a list of species identified as being of conservation importance, and their likely annual quantities and seasonality
- a list of potential nuisance species (weed, jellyfish, sprats, etc), that may inundate the screens and cause operational problems to the power station, together with a description of risk factors for each (geographic areas or features of highest risk, seasonality, conditions under which they present highest risk).

4 Using the output: significance and method

4.1 Significance: station operation

The significance of the impingement has to be judged in statistical, ecological and socio-economic terms, whereby each of these aims to detect and, where possible, quantify a 'signal' (the required change in the population or community to be detected) against the inherent 'noise' (background variability) in the system.

4.1.1 Context

- what is the financial cost to the power station?
- what are the health and safety issues for the power station?
- are there issues regarding the aesthetics and perception of the impingement?

4.1.2 Method

Having established species that may present risk, the station design team needs to be advised of risk factors. Key factors to consider are:

- areas of high versus low risk for location of CW intake structure (eg, avoid backwater or upper estuarine areas where eddy currents might cause weed to accumulate)
- any difference in intake type, position in the water column or opening depth that would affect risk
- any aspects of intake or screen design that might make the station more or less vulnerable (eg, 10 mm drum screen mesh can deal with ctenophore inundations better than 3 mm mesh, as they can penetrate and be washed back to sea with the CW)
- any available mitigation techniques and their suitability for the site (and if mitigation is not possible then compensation of the users (fishermen), species (by restocking) or the habitat (by habitat re-creation) will have to be considered)

It should be possible to estimate potential ongoing financial revenue costs associated with handling and disposal of impingement wastes based on predicted quantities and their seasonality/periods of high loading. In addition to the transport and labour handling costs, the Land-fill Tax for highly organic waste is higher than for inert materials (cf. at 2009–10 rates of £40 per tonne for active waste and £2.50 for inactive waste). Costs may be reduced by incorporation of suitable mitigation measures, some of which are likely to be required anyway for ecological conservation. The waste could have benefit in composting or biological use schemes (eg, fertilisers, biogas digesters, etc), although as yet power station trash has not been included in these disposal methods.

Health and safety issues should be avoidable by suitable FRR design so that biological detritus is not retained on site. However, this may be only partially achieved where FRR systems are designed to separate fish from trash, the latter still requiring disposal to landfill.

4.2 Significance: ecological

4.2.1 Context

- commercial sizes and species
- disturbance of the ecology
- conservation importance

4.2.2 Method: commercial

Assess the significance against commercial statistics.

A number of studies have been carried out to assess the significance of impingement in the commercial fisheries context. These studies have adopted various contextual frameworks, eg, to commercial landings of fish or mortalities associated with discarding non-target or undersized fish at sea (see, for example, Turnpenny and Taylor, 2000).

The steps involved are:

1. predict the annual catch rate and age composition for the key commercial species
2. apply year-class abundance standardisation as described by Turnpenny and Taylor, 2000)
3. convert predicted catch rates to Equivalent Adult Values (EAV; see Turnpenny, 1988)
4. add EAVs from fish entrainment estimates to give combined entrainment and impingement figures
5. express standardised annual entrainment and impingement catch rates (as EAVs) as percentages of the landings from adjacent ICES sea areas (see Turnpenny, 1988)
6. assess significance according to environmental impact assessment criteria.

EAV analysis requires the construction of fish lifetables, which contain species- and lifestage-specific data on mortality rates, fecundity, sex ratio and other parameters. Ideally, lifetable data would also be specific to the sea area adjacent to where the power plant is located. To date, lifetables have been developed only for a limited number of species and only in certain sea areas. A further limitation of the EAV method is that no means of computing confidence limits of EAV estimates appears yet to have been considered.

4.2.3 Method: ecological

- apply WFD multimetrics for Transitional Waters (Coates *et al*., 2007) – in the absence of a WFD fish tool for coastal waters, an alternative is to apply the Transitional Waters tool
- trophic assessment – estimate equivalent area of lost production (Habitat Production Foregone [HPF], California Energy Commission, 2005; Turnpenny *et al*., 2010)
- apply Marine Strategy Framework Directive (MSFD) metrics for coastal water when they become available
- establish individual species case studies: eg, sand smelt (Henderson *et al*., 1984) and brown shrimp in the Severn Estuary and east coast (Turnpenny and Taylor, 2000)

A multimetric method of fish community assessment has been developed for WFD application on transitional waters. This tool is intended for use in <u>assessing</u> Ecological Status, and cannot generally yet be used for <u>predicting</u> changes in ecological status as a result of a changed level of impact. No equivalent procedure has yet been developed for coastal waters, but may emerge through the implementation of the MSFD.

Various ecological assessment techniques are presented by Turnpenny *et al.*, (2010). Perhaps the most useful is the HPF concept, originally used to assess entrainment and impingement losses at California's directly cooled stations (CEC, 2005), a method that allows quantities of fish removed by power stations to be equated to the equivalent area of marine habitat being taken out of production. This is particularly suited to considering ecological requirements in compensation for residual impacts once other mitigation measures have been applied. Table 1 gives indicative figures for Californian stations.

Table 1 California Energy Commission figures for habitat areas that would be required to replace entrainment losses at Californian power plants (California Energy Commission, 2005). Plant CW flow shown for comparison

Plant	Flow rate (cumecs)	Area of replacement habitat (Ha)
Diablo Canyon	127	120–240
Morro Bay	33	93–307
Moss Landing	61	460
Potrero	11.3	357
San Onofre	52	61

Habitat production figures can be obtained from the literature, although not always for the particular geographic area in question. For example, work carried out on saltmarsh habitat by Nixon and Oviatt (1973) at Bissel Cove, New England, USA, estimated net export production of the saltmarsh at 250 kJ m^{-2} y^{-1}. Assuming this went into fish production with an energetic value of 4.5 kJ g^{-1}, each square metre of saltmarsh would support 56 g y^{-1} in fish production.

As an example closer to home, fish production (total biological production) for the North Sea as a whole has been estimated at 2,500 kg km^{-2} y^{-1}, while estuarine production estimated for the Forth was 4,300 kg $km^{-2}y^{-1}$ (Elliott and Taylor, 1989). Equivalent figures have been obtained for other water bodies (see Elliott & Hemingway, 2002, for production estimates for species and communities in other European estuaries). These figures can be applied directly to power station fish catch estimates. For example, 43 tonnes of fish per year impinged at Sizewell Power Station (Turnpenny and Taylor, 2000) equates to an equivalent area of lost North Sea production of 17.2 km^2 on this basis.

A similar approach was used by Turnpenny (2002) in the context of Fawley Power Station (Hampshire), where it was estimated that the annual catch of impinged fish at a CW flow of 32 m^3 s^{-1}, expressed in Equivalent Adult terms, was 424 kg y^{-1}. Using production figures for the Forth Estuary given by Elliott and Taylor (1989), this is the equivalent to lost production of 9.9 ha. Comparison was made with the Forth Estuary owing to a lack of any more local data on estuarine production; it should be noted that this was based on the whole area of the Forth Estuary, including sub-tidal areas.

Individual species case history studies have provided an effective tool for investigating non-commercial species. In a series of papers, the CEGB Fawley Marine Laboratories (Bamber *et al*., 1983; Henderson *et al*., 1984; Turnpenny *et al*., 1981) examined the population dynamics of the sand smelt, *Atherina presbyter*, a short-lived species, that forms relatively small, discrete populations with little interchange. This was the most commonly impinged species at Fawley Power Station, with catches of >10^5 individuals per year, and it was expected that a fish with such population dynamics would be most likely to show signs of over-depletion. However, it was concluded that the population had remained stable after 10 years of power station operation.

Another single-species study, on the brown shrimp *Crangon crangon*, was carried out by Henderson and Holmes (1987) in the context of the Hinkley Point Power Stations. The authors estimated the potential annual impingement rate of shrimps at the stations and the population size for the local Stert Flats stock. The power station catch was shown to be equivalent to <9% of the local stock. A more recent study (Henderson *et al.*, 2006) has further investigated *Crangon crangon* population dynamics at Hinkley Point Power Station.

4.2.4 Method: conservation

- Deliver information for an Appropriate Assessment (Habitats Directive) or any other conservation importance
  - list the conservation objectives for the area in question
  - determine how the power station affects the conservation objectives
  - carry out a population dynamics assessment for individual species re conservation status

European protected sites (Special Areas of Conservation – SACs – and Special Protection Areas – SPAs) that form part of the Natura 2000 network are listed, along with their conservation objectives, on the Joint Nature Conservation Committee website (www.jncc.gov.uk/). Power stations that lie outside protected site limits can still be affected by the protections. For example, a site adjacent to an SAC may be on the migratory path of species that fall within the conservation objectives of that SAC. It is of note that there is an increasing body of case work testing the spatial limits of appropriate assessment analysis, ie, a plan or project in one area outside the designated SAC but with the potential to affect the conservation objectives for which the SAC was designated, eg, as an extreme the effects of the Maasvlakte 2 port expansion in Rotterdam affecting the SAC of the Wadden Sea several hundred kilometres further north.

Having identified any protected species, it must be demonstrated that construction, operation and decommissioning of the power station will not adversely affect the conservation objectives for the site. The case must be made for each and every species, habitat and assemblage listed in the protected site designation and may require the development of appropriate population dynamics models. Examples of approaches used in relation to entrainment and impingement at power stations can be found (eg, Horst, 1977).

4.3 Significance: social

Social factors cannot be ignored when assessing the significance of potential fish kills or losses. While it may be possible to demonstrate that fish losses are negligible in economic or ecological conservation terms, public perceptions are important and may hold up the planning process or cause bad publicity once a station is operating. To some extent, the public concerns are best dealt with by presenting a sound scientific case in ways that the public can easily understand. Formal metrics can be applied to assess social concern, as was done in making the case for the Thames Tideway Tunnel, where an economic evaluation of the public's concern over fish kills in the Thames Tideway was expressed in terms of 'willingness-to-pay' (WTP). The WTP process canvassed public opinion to assess how much individuals would be prepared to add to their water rates in order not to have fish kills in future. Such techniques do not appear to have been applied within the power industry context, but may be appropriate where public opinion appears to be forcing developers to adopt mitigation measures that are above and beyond what scientific analysis indicates to be necessary.

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Appendix A Definitions

A.1 Methodology

In this case a methodology is a structured compilation of the activities (defined by a set of methods) required to achieve an understanding of the particular subject with respect to NNB.

A.2 Methods

Methods, in this case, refer to activities and ways of doing them. They range from accepted field measurement protocols to consultation through to experimentation.

A.3 Impingement

Impingement is the retention of organisms on power station CW intake screens.

Appendix B Sampling to estimate annual impingement amounts, types and rates

B.1 Purpose

During the operation of power stations, fish, mobile invertebrates (eg, jellyfish, copepods, mysids) and drifting algae, including eggs and larval stages, will inevitably be drawn in with the cooling water supply (Figure 1 and Figure 2). Depending on the size of the drum screen meshes (often 1 cm^2) (Figure 3), fish that are too large to pass through will become impinged on the screens, while smaller individuals, including the egg and larval phases, will be entrained into the cooling circuit and returned (live or dead) to the wild.

In order to assess the potential impact of such losses and to design appropriate mitigation measures, a suitable quantitative sampling programme needs to be carried out to estimate **annual loss rates** due to both impingement and entrainment. This must take account of cyclical (diurnal, tidal and seasonal) and random variation, and annual patterns, and of possible biases caused, eg, by sampling location within the plant and by sampling. Hemingway and Elliott (2002) describe this and other fish sampling methods and give case studies of the methods in use.

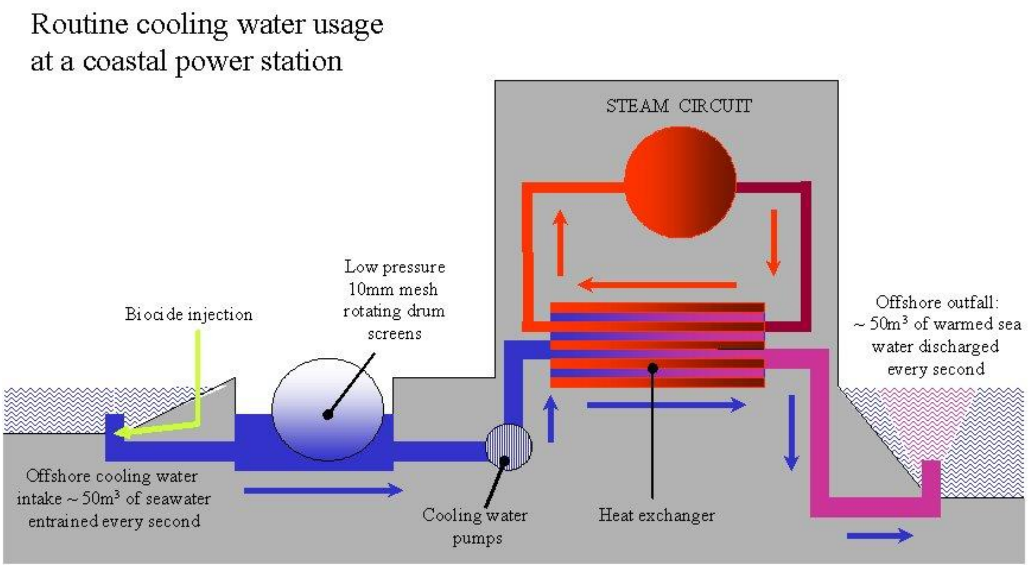

Figure 1 Schematic figure of direct-cooled CW system

Figure 2 CW intakes (Heysham Power Station)

Figure 3 Drum screens showing back-wash culvert (lower left corner) (Torness Power Station)

Figure 4 Trash basket showing weed, litter and lumpsuckers

B.2 Impingement sampling practicalities

B.2.1 Where to sample

Samples of impinged fish are collected from the drum or band screen backwash stream at some point downstream of the screen backwash outlets (Figure 3). Where the discharge would normally enter an in-line trash basket (Figure 4), samples can be collected from the trash basket. However, it is usually preferable to intercept samples at an earlier point, typically by placing custom-fitted Netlon™ baskets into the backwash gulleys beneath the cascade from the backwash hopper. There are usually convenient guiding rails on which to attach the baskets if they are attached to metal frames. This avoids Health and Safety issues associated with entering large trash baskets and ensures that the samples are fresh. It also breaks the overall catch down into smaller subsamples that are convenient for handling. While sampling trash baskets in cold weather is not difficult, doing so in hot conditions, and especially where the trash has accumulated over a few days, is unpleasant and potentially health-threatening.

Sampling of trash baskets requires operators to be closely involved in the sampling. If there are two or more baskets then water can be directed to these in sequence so that they sample for a well-defined period. For example, one day before a visit, one of the baskets can be emptied and the backwash water directed to it to produce a 24-hour sample.

B.2.2 Subsampling

Experience has shown that, where a number of travelling screens are used, the fish and trash loading is generally not uniformly distributed across the screens, often showing a bias to one side. Therefore, for quantitative sampling, it is essential to sample from all the working screens. Where subsampling is considered necessary, one of the following methods should be used, eg, for a 25% subsample:

- sampling for a part of each hour – collect material for the first 15 mins in each hour (only suitable where round-the-clock manning is used).
- mix and quarter the material collected over the whole period. (Note: where a small number of larger fish are present, it is better to remove the larger fish first and count these in total, then process the subsample and combine the numbers with the appropriate raising factor).

B.2.3 Sample processing

It is preferable to process fish impingement samples on site while fresh. This ensures that fish are in the best condition for identification and avoids the need for working with toxic preservatives. Sometimes the catch processing involves weighing (condition estimates) or dissecting individuals (maturity status, feeding condition), which are best conducted in the laboratory since most structures are open and exposed to the elements. Where identity cannot be confirmed on site, they should be returned to the laboratory, either chilled in a cool-box, frozen or, under extreme circumstances, preserved in 5–10% (depending on the ratio of liquid to vessel volume) buffered formosaline solution. For example, small juvenile fish (especially clupeids), soft bodied invertebrates and most planktonic organisms will decay quickly or will be greatly damaged by freezing, thus making identification impossible unless fixed.

The following observations should be recorded for each species in all cases:

- date of capture.
- species name.
- total number and weight of specimens over the 24-hour period (raised from subsamples if necessary)
- Standard length (snout to caudal peduncle – preferred measurement since fins may be damaged) for all fish or a subsample of 200 fish if more than 200 present. (There should be conversions from standard to total length post-survey; large numbers of fish may have to be preserved or frozen for later analysis given time constraints.)

Optional additional data may include:

- a breakdown of the above into hourly subsamples (it is often more convenient to process samples hourly, therefore useful to retain the temporal variation data)
- observations of scale loss, fin damage, other abnormalities and other lesions, including digital photographs
- dissection to identify swimbladder damage
- other data on fish health and sex ratio if easily obtained (eg, see Figure 4, which shows the smaller male and larger female lumpsucker).

The second two of the optional items can provide useful information on fish-handling performance of the travelling screens.

The remaining trash material should also be noted either as abundance or volume or, as a minimum, presence: litter, seaweed, shrimps, other large invertebrates (jellyfish, ctenophores, cephalopods, macrocrustaceans, etc). A simple SACFOR scale (superabundant, abundant, common, frequent, occasional, rare) will be adequate for the latter purpose. It is best, however, to preserve a small calibrated subsample if resources allow for the more detailed analysis. Note that seaweed quantity may indicate recent weather conditions, and the composition of the invertebrates will indicate the position of the intakes and the behaviour of the organisms. In addition, record any other information about the plant, including the position of intake in the water column and whether it is adjacent to or away from the shore, the nature of the bed around the intake, the presence of smolt and bar screens and the frequency of use of the former, etc.

Physico-chemical water quality parameters should be recorded on site where possible as they are useful additions to the biological data. Similarly, records should be kept of routine maintenance operations that often result in the reduction of the intake volume and are likely to affect impingement and entrapment levels. A confirmation of the flow rate through the screens during sampling is always needed, and any deviation from the operation capacity noted.

B.3 Impingement survey design

B.3.1 Statistical requirements

The statistical validity and precision of several sampling methods for impingement estimation has been discussed by Murarka and Bodeau (1977) and Murarka *et al*. (1978). These studies demonstrate that stratified systematic random, systematic random and stratified random sampling schemes (see below) offer higher efficiency and improved precision when compared with purely systematic sampling (eg, on the first day of every month). The randomised component is therefore important. A complete statistical design, in which replicates are required in order to allow ANalysis Of VAriance (ANOVA) or power analysis to detect a given departure from a given standard, is unlikely to be needed. However, if the main objective is to define a significant change over time, then a minimum of three replicates will be required for ANOVA followed by post hoc analysis. In these cases, rigorous hypothesis generation and testing is required (see Fowler *et al.*, 1998; Elliott *et al.,* 2002; Dytham, 2003).

Stratification is a device used for incorporating existing information about impingement patterns into the sampling design to improve precision. For example, where the timing of a migration that leads to seasonal impingement of a given species is known, sampling effort can be intensified in that season.

Systematic designs break down the sampling year into a number of equal units – usually months or quarters, within which the dates are randomly selected. Alternatively, sampling can be conducted every *k* days (eg, weekly, where *k* = 7), provided that the first sampling date is chosen at random to reduce design-related bias. The pump operation should be recorded as there are many occasions when data analysis is compromised because of erratic pumping or even shutdowns prior to sampling.

For surveys that are intended to estimate annual impingement rates across all species, a systematic random design, in which a number of dates are selected at random within a given month or quarter, offers a good solution.

B.3.2 Sampling Intensity

Sampling on forty dates per year (~11%) has been common practice, based on US power plant studies (Murarka and Bodeau, 1977). It is suggested that this intensity of sampling is retained as a minimum for all future BEEMS studies.

Various datasets containing large numbers of 24-hour sample data are available for different UK power plant sites, including those of interest to BEEMS. It would be beneficial to apply statistical power analysis techniques to some of these datasets to assess the adequacy of this sampling intensity against specific project objectives. Again, depending upon the area and species composition and survey objectives, some periods will require better resolution and hence shorter intervals between samples. Conversely, less-active periods such as winter months could be efficiently and effectively covered with fewer samples.

B.3.3 Avoiding diurnal and tidal bias

Impingement patterns are strongly influenced by tides and diurnal factors as well as other biological factors such as spawning migrations (eg, Figure 4 shows a number of lumpsucker *Cyclopterus lumpus* impinged after an unusual inshore spawning migration). Tidal conditions can have several effects on impingement rates, including movements of fish past the CW inlet, concentration of fish into tidal inlets at low water (LW), increased screenwell clearance efficiency at LW, variations induced in intake velocity, etc (Turnpenny and Utting, 1988). For shoreline intakes drawing, catch rates are often maximal towards LW due to concentration effects, whilst at offshore intakes, rates tend to peak at mid-tide when tidal stream velocities are highest (Turnpenny, 1988).

In the case of estuarine intakes, migrations of diadromous species will be detected depending on the position of the intakes (eg, adjacent to the shore or in the main channel), therefore a knowledge of the importance of migration runs is required especially where these may be short but intense pulses.

Strong diurnal patterns are also commonly seen. These result from diurnal variations in fish activity, and from loss of visual orientation at night. Diurnal effects are often much reduced in turbid estuaries where visual orientation may at any time be poor (Turnpenny, 1988).

Diurnal bias and short-term (~13-h cycle) tidal bias are eliminated by selecting 24-hour sampling units. Longer-term tidal bias is eliminated by randomising sampling dates. Spring-neap cycles and proximity to equinoctial tides will all indicate the volume of water passing the plant and thus the amount of fish liable to impingement.

It should also be remembered that some intake structures are designed to increase natural avoidance behaviours; this includes screen orientation and CW intake location to reduce impacts. These could also introduce bias in the entrapment levels of certain species.

B.3.4 Sampling design for previous UK surveys

It should be noted that previous surveys at coastal and estuarine power plant sites have been conducted with different objectives in mind, some of which are not compatible with estimating annual entrainment rates. Long-term surveys carried out by the Environment Agency and its predecessors at West Thurrock Power Station on the Thames Estuary were designed to provide the largest possible samples per unit of sampling effort (Thomas, in Attrill, 1998); Elliott and Hemingway, 2002). They were therefore conducted on falling spring tides, when impingement tends to be maximal. This approach maximises the ability to detect rare species and provides the most statistically robust method for following long-term trends in fish impingement rates. A similar, tidally-biased, approach has been used in the long-term fish surveillance programme at Hinkley Point Power Station. Such a design limits the value of the data for annual quantification, although statistical corrections can be applied through studying the relationship between the segment of the day/tide sampled and that for the whole 24-hour period.

Sampling designs for annual impingement rate assessments have been used at several UK sites, eg, the joint CEGB/Cefas surveys conducted at Sizewell A Power Station in the late 1970s (Turnpenny *et al*., 1983). Based on advice of Murarka and Bodeau (1978), a sampling intensity equivalent to 40 x 24-hour periods per annum was chosen. The effort was deployed in quarterly blocks of 10 dates, which were randomly selected within each quarter. Weekends were excluded for practical reasons, but no operational bias was expected from this as the stations were normally operating at base load (ie, continuously), with no weekly pattern. This can be described as a ‘stratified systematic random’ sampling procedure, although the absence of weekend working could result in some tidal bias.

Subsequent annual quantitative surveys conducted by the CEGB and its successors have broadly followed this approach, with minor variations. For cost reduction, these have sometimes involved sampling in monthly blocks of three to four non-weekend days, to give the 40 x 24-h samples. In this case, the random element has been with respect to selection of the blocks of dates within each month, the months providing 12 sampling strata within the year.

In other cases, a stratified-random approach has been used to weight the effort according to the known seasonality of impingement. At sites where it has been observed that peak impingement occurs over the spring or autumn months, sampling may be increased to fortnightly or even weekly over key periods, with perhaps only 2 x 24-h periods per month in ‘low’ periods. Such an approach is best suited to surveys that are designed to focus on individual species or groups of fish, such as migratory salmonids, shads, eels or bass.

In Belgium, the fish and macrocrustacean community of the Westerschelde has been studied during the winter period 1991–1992 using samples obtained from the Doel Nuclear Power Plant situated on the Scheldt Estuary (Hemingway and Elliott, 2002). This power station has five intake culverts, which form a construction that is 21 m in diameter. The external openings are situated 2 m above the bed of the estuary, and water pumped at up to 0.5 ms^{-1} is collected within a tank. Screens primarily filter the water to remove debris and larger fish, and then rotating filters (with a mesh size of 4 mm) filter the water again before it is pumped to the cooling system of the plant. High-pressure water jets clean the filters, and this water is captured and brought via a ‘canal’ to a reservoir. Samples were taken within this ‘canal’ using a net with a 2.5 mm mesh size. Sampling lasted between 8 to 10 minutes and the sprinklers continuously cleaned the rotating filters throughout (Maes, 2000).

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British Energy