Pisces Conservation Ltd.

Technical Evaluation of US Environmental Protection Agency Proposed Cooling Water Intake Regulations for New Facilities

Prepared by Drs P. A. Henderson and R. M. H. Seaby,

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IRC House
The Square
Pennington
Lymington
SO41 8GN
England

Pisces@irchouse.demon.co.uk
www.irchouse.demon.co.uk
Phone 44 (0) 1590 676622
Fax 44 (0) 1590 675599

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1 Introduction

Background

On August 10, 2000 the United States Environmental Protection Agency (EPA) published proposed regulations to govern the development and operation of cooling water intake structures at new facilities. (See 65 Fed. Reg. 49059, August 10, 2000). The agency derives authority to promulgate the regulation from the Clean Water Act, and is in part required to do so as the result of a consent order entered into before federal district judge Allen G. Schwartz of the Southern District of New York. Section 316(b) of the Act requires any permit issued under the National Pollutant Discharge Elimination System to ensure that the "location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimising adverse environmental impact." 33 U.S.C. §1326(b). The purpose of the proposed regulation is to implement section 316(b) by describing the best technology available for minimising such impact.

In this report, Pisces Conservation Ltd (Pisces) has reviewed and evaluated the ecological basis for the proposed regulation. Pisces is a British ecological consultancy specialising in the ecological effects of industry and power stations in particular. As described more fully in Attachment A, Pisces has extensive experience consulting on the ecological impacts of power plants, including in particular the impacts of cooling water intakes and thermal discharges on the biota of surrounding waters.

The ecological effects of cooling water intakes have been of serious concern for more than 40 years. Since the electricity industry is the single largest user of water in all developed parts of the world, the greater part of our scientific knowledge on the ecological impacts of cooling water intakes is derived from studies of power plant cooling water systems.

Analytical and historical notes

There are considerable difficulties in predicting or even measuring the ecological impact of cooling water systems. Key reasons for this have included a limited understanding of the population size and dynamics of fish and other aquatic life, the difficulty of obtaining reliable estimates of impingement and entrainment and a longstanding failure to accurately correlate levels of mortality to population or ecosystem effects.

Further, typical studies of industrial impacts have been of only limited utility in quantifying predictive relationships because they have focused on site-specific levels of impingement and entrainment observed, which can also vary greatly between location and years. Thus insights gained from short-term studies of a limited number of intakes can seriously mislead when extrapolated over time or used as guidance in other locations. The deterioration in measures of ecosystem health such as species richness or trophic complexity can be quite gradual and irregular and take many years to recognise. The trend is easily lost in random variation caused by events such as exceptionally cold or warm spells or lost within other man made changes such as eutrophication and acidification.

However, considerable data has been collected on entrainment and impingement mortality of aquatic life, indicating that the mortality caused is great. A conservative management regime should avoid these impacts if possible. Some clear general principles have emerged regarding the factors influencing the ecological impact of cooling water intakes, and techniques available to minimise these impacts. For example, as we demonstrate in Section 3, minimisation of total flow is almost always effective in reducing entrainment and impingement, especially where reductions are taken from once-through systems. The combined results of N. American and European studies produces a sizeable body of knowledge on which to base an analysis of the effects of cooling water intakes and cooling systems. To optimise our general conclusions we have use a wide range of available data covering disparate environmental situations.

The European state owned electricity companies such as the Central Electricity Board in Britain established major research laboratories which accumulated considerable knowledge on the ecological impacts of cooling water intakes and closed circuit cooling systems. In Northern Europe, high population densities resulted in extreme demands on water usage in relation to the available supply. By the 1960s In England and Wales for example, cooling water demand represented over 50% of the average freshwater run-off and exceeded the total dry-weather flow of all major rivers. Such extreme demands focused attention on ecological impacts and required closed cooling water systems at freshwater sites. It also focused the development of large nuclear and conventional power plants with once through cooling at ocean and lower estuarine localities. In the final phase of the development of power plant with direct cooling large (2000 MW or more) power station complexes were sited on coastal sites. The largest such development was the 5400 MW Nuclear Power Station at Graveline, Northern France. A similar trend towards the concentration of direct-cooled power stations in estuarine waters has also occurred in the USA, as shown, for example, by developments on the Hudson estuary. In terms of their environmental impact, the power plants on the Hudson and in Britain have been some of the most intensively studied in the world.

Typically, much of the focus in both N. America and Europe has been on the effects of impingement and entrainment of fish populations. While the two continents have only a limited number of fish species in common the North Atlantic fish fauna on both sides of the ocean share many ecological features and possess many similar species. They show the same feeding guilds, trophic organisation, seasonal patterns and dominant species with remarkably similar life-styles. For example both European and N. American rivers are used by migratory shad and juvenile marine species of flatfish and gadoids. Similarly, their temperate freshwater fish faunas have much in common.

There are also some clear differences. First, fish communities in N. America are often more species rich, which may in part be linked to the comparatively large size of some N. American lakes and rivers. Second, US waters extend to tropical latitudes and include Pacific Ocean waters. While ecosystem structure in temperate latitudes in both the Pacific and Atlantic Oceans have much in common, there are issues that are of particular concern in tropical and sub-tropical waters for which European data

cannot contribute. Possibly the most important of these is the increased sensitivity of tropical and sub-tropical systems to thermal pollution.

Finally, recent European experience may be useful and relevant to US decision makers because cooling systems that minimise extraction from natural waters have long been more commonly used in Europe that N. America. There has been a considerable recent shift in the design of power plants in favour of gas turbine, often combined cycle, stations with significant reductions in cooling water requirements. Within Britain, this was associated with the deregulation of the industry in the 1980s, as it is now in many areas of the U.S. Combined cycle gas turbine stations now in operation include Rye House, Dam Head Creek, Deeside, Didcot and Connors Quay. Rye House and Dam Head Creek use dry cooling, while the other three have evaporative cooling towers with small volume intakes protected by wedge wire screens. A considerable number of dry cooling stations are also in operation in other European countries including Slovenia and Germany. Similar trends are also apparent in N. America.

2 Location

The proposed regulations classify waters in four types, (1) rivers and streams, (2) lakes and reservoirs, (3) estuarine and tidal rivers and (4) ocean. The most important result of this classification is that different types of water body will be subject to different regulations and thus differing levels of protection. All four classes of water body are of high ecological merit and hold communities that are vulnerable to damage and degradation by inappropriate water extraction and discharge. In the case of river, lake and ocean sites with sub-littoral intake points, the regulation would permit once through cooling, which is by far the most damaging to aquatic life. While a case can be made for once-through cooling in artificial impoundments and reservoirs built to serve as cooling ponds, this type of water body has not been distinguished from natural lakes. We question the EPA's basis for discriminating between these types of water body either in terms of their ecological value or ability to withstand stress.

The highest level of protection, including a closed cycle-equivalent flow, is offered for estuarine sites and the littoral zone for ocean, lacustrine and riverine waters. A small (50 m) buffer for the lacustrine and riverine littoral zone is included in the closed cycle-equivalent flow requirement. The lowest level of protection, allowing for once-through cooling, is permitted for all other ocean, lacustrine and riverine waters.

A consideration of the applicability of this distinction serves to emphasise the arbitrary nature of the proposed classification in terms of ecosystem protection. The regulatory scheme appears to be based on generalised characterisations of the different types of areas (*e.g.* estuaries and littoral zones are often considered the most productive per unit volume). However, the ultimate classifications and respective level of protection afforded bears little relation to the ecological dynamic present in those waters.

Proposed delineation of ocean and estuarine areas

The proposed regulation defines ocean sites as localities with salinity at or above 30 parts per thousand (ppt). Full ocean water has a salinity of about 34 ppt so this definition will include coastal sites close to and within the mouths of estuaries. The

definition as given does not refer to the temporal variation in salinity. In estuaries and their adjacent coasts salinity varies both tidally and seasonally. Lower estuarine sites can vary in salinity from 20 to 32 ppt over a single tidal cycle and estuarine waters can vary from 5 to 32 ppt between seasons. If the 30 ppt criterion is not increased then it would result in large areas of estuarine waters becoming classified as ocean waters. Even if average salinity were used it would result in lower estuarine habitat and the mouths of rivers receiving the lowest level of protection. Such areas are just as important for young fish as more internal estuarine waters, and many species show a gradual movement to marine waters as they develop. Therefore, as will be discussed in more detail below, there is no clear distinction between estuarine and marine nursery areas. The use of the 30 ‰ salinity level to distinguish ocean from estuarine water is arbitrary and does not separate distinct and unconnected ecosystems.

Proposed level of protection in estuarine and non-estuarine waters

Estuarine habitats are used by a large number of fish and crustacean species for part of their life cycle. They are particularly important nursery areas and because of this function there has been considerable concern about the loss of juvenile fish on cooling water intakes in estuaries such as that of the Hudson River (Barnthouse, Klauda et al. 1988). However, many of these estuarine inhabitants will spend part of their life, usually as adults and juveniles, in marine waters. The striped bass is a good example of a fish that may use estuaries in this manner. Migratory species move between estuarine and marine waters seasonally and tend to follow particular routes. The proposed regulations would offer such species more protection during the estuarine than during the marine phase of their life. While this can be appropriate if, for example, the estuarine phase is particularly localised into a restricted zone of low salinity where it would be highly vulnerable to entrainment, this need not be the case. For fish such as migratory clupeids, it is possible to envisage situations where intakes situated outside of the littoral zone, in waters at or above 30 ppt, would be situated in channels used by returning migrants resulting in large-scale moralities. Another way in which fish and crustaceans can become particularly vulnerable to intakes placed in ocean water is during the winter when many species retreat from cold estuarine and littoral waters into warmer, deeper, ocean waters.

Such considerations lead to the conclusion that there can be no general biological basis to afford ocean waters (as defined in the proposed regulations) lower levels of protection than those offered to estuaries. This disparate treatment is especially problematic given the respective levels of protection afforded the two areas. As described more fully below and in the preamble to the proposed rule, there are up to two orders of magnitude difference in the level of entrainment between once-through cooling and wet cooling systems, and up to four orders of magnitude difference between once-through and dry cooling. EPA has suggested nothing, and we know of know data, to indicate that any supposed distinction between estuarine and ocean waters in terms of entrainment mortality remotely approaches this level of magnitude.

The same problem with the proposed regulation besets lacustrine and riverine waters outside the littoral buffer, since the capacity requirements applicable to the sub-littoral ocean would also apply to these fresh waters. Again, EPA has suggested nothing, and we know of know data, to indicate that any supposed distinction between estuarine and deep fresh waters justifies the installation of once-through cooling for the latter.

The effects of intakes within and outside the littoral zone

A key aspect of the proposed regulations is the position of the intake with respect to the littoral zone. For freshwaters, the littoral zone is defined as the zone from the highest seasonal water mark to a depth at which (1) light is at 1% of ambient, (2) there is no significant change in slope and (3) there is no significant change in substrate. For ocean waters, it is defined simply as the euphotic zone.

In the case of lake and ocean waters, an intake placed outside the littoral zone (> 50 m for lakes) requires an intake velocity no more than 0.5 ft s^{-1} and other requirements under 125.84(f) and (g) which relate to multiple intakes in the area, the presence of regionally important species and the attainment of water quality standards. Thus direct-cooling is permissible and the only protection to reduce fish and crustacean entrainment and impingement is the restriction on maximum intake velocity across the filter screens.

The first point to note is that the littoral zone is defined in terms of light penetration, but this can vary greatly between seasons and even between days. Turbid waters, or those with high plankton densities, can have a highly restricted photic zone, but can still support a rich ecosystem in their sub-littoral. In turbid waters, such as those near the mouths of estuaries, the photic zone may extend little beyond the extreme low water mark. In such situations the proposed regulation could allow a once-through intake to be positioned close to the beach. As EPA points out, the littoral zone is often of high ecological productivity and is used as a feeding area by many fish and crustaceans, particularly juveniles. However, at low water and particularly on spring tides, organisms must retreat from the littoral and thus may move directly into the vicinity of the intake. Furthermore, their natural tendency is to move with the current so that they leave any areas that may become dry or too shallow. Thus, they may follow the current directly into the intake. Large predatory fish are often loath to enter the littoral and tend to hunt in the near sub-littoral where they often feed towards low water when smaller organisms retreat from the littoral. Their area of highest density will therefore tend to be in the vicinity of sub-littoral intakes. In some circumstances they may actually use the region of flowing water around the intake as a hunting ground, aggregate around any intake structure and depending on intake design and screen size they may follow their prey into the intake pipes from which they cannot escape. Thus it is impossible to protect the fauna of the littoral by positioning intakes in the near sub-littoral. Further, the presence of the intake structure will alter the local ecology.

For estuarine and ocean waters there is no support for the view that entrainment and impingement at once-through cooling water systems can be appreciably reduced by siting the intakes in the sub-littoral as many examples can be cited of high catch rates at such intakes (e.g. Henderson 1989). On the contrary, there are numerous examples of the use of near shore sub-littoral ocean habitats as nursery grounds. These can be particularly important for juvenile flatfish that after metamorphosis initially settle in deeper water before moving into the shallows. A clear example of a fully marine habitat that is used as a nursery by young fish are Zostera beds, which are particularly important in tropical and sub-tropical waters.

Two studies illustrate the level of impingement at ocean sites, and the difficulty of achieving reduction. Units 2 & 3 of the San Onofre Nuclear Generating Station

(SONGS) in southern California have a once-through cooling system with water extracted from an offshore intake at a flow rate of 13,833 gallons s^{-1}. To minimise fish impingement mortality a fish return system is used in which the fish are diverted, elevated and sluiced away from the filter screens. Love (1989) undertook a study of the efficiency of this fish return system. For 1984, the total number of fish estimated to be entering the cooling water system was 196,978 of which 188,583 were returned and 8,395 impinged. For 1985, the total number of fish estimated to be entering the cooling water system was 407,755 of which 306,200 were returned and 101,555 impinged. However, not all of the returned fish would have survived as the 96 hr survival rate of *Anchoa compressa*, *Anchoa delicatissima*, *Genyonemus lineatus* and *Seriphus politus* were around or below 50% and these species are amongst the commonest species caught. Moreover, the ability to survive in a recovery pen may still overstate the efficiency of the return system as waiting predators may eat the returned fish. Love (1989) state that "Small groups of barred bass and kelp bass and solitary California halibut congregate near the discharge, having apparently associated the conduit opening with food. However, it is infrequent visits of schooling predators such as jack mackerel, Pacific mackerel and large *Scomber politus* that appear to result in the largest predation pressure. We observed schools on 13 of 80 days of observations on the return system's discharge." This tendency for intakes and outfalls to attract predators is also considered above in the Section on ecosystem effects.

The second example is the study at Sizewell A & B Nuclear Power Stations on the English coast which demonstrates the level of reduced fish impingement mortality that can be achieved at a direct-cooled ocean site (Fleming, Seaby et al. 1994). The B station intakes were carefully positioned offshore; they were fitted with a velocity cap; the intake structure was minimised to avoid attracting fish; and the station was fitted with a fish return system. As in the case of the SONGS return system, it was not possible to save many of the pelagic fish, particularly clupeids. Seaby (1994) found that while flounder, plaice, sole dab and bass had survival rates greater than 80% after release from the fish return system, survival of whiting, sprat, herring and pout was much lower. In the case of the pelagic sprat and herring survival was negligible. An important observation was that fish that have a sealed swim bladder (physoclists) were highly vulnerable to abrupt pressure changes and frequently suffered fatal swim bladder damage. This was not the case for species with swim bladders that open to the gut (physotomes). When water is extracted from the sub-littoral animals entering the system will inevitably suffer abrupt pressure changes, which for some species will be fatal. The result was a 50% reduction in impingement deaths compared with the A station that had none of these features. However, the station still killed many millions of fish per annum. Furthermore, no improvement in entrainment mortality was produced.

Furthermore, any large structure on the sea or lake bed will attract some types of fish and crustacean. The reasons are complex but include shelter from currents, predator avoidance or food resources brought to the area or growing on the structure. Thus intakes can influence the local ecology and the fish they catch may not be the same as those that would live in the area if the intake were not present (See Section 4 below for an example of a design where the superstructure was minimised). An example of a species using an offshore intake structure is given by Benda *et al*. (1975). They found that the crayfish, *Orconcetes propinquis*, inhabited the intake crib of the Palisades Power Plant on Lake Michigan (the crib is a 17.4 m long, 17.4 m wide, 3.7 m high

structure located 1000 m offshore 6.1 m below the lake surface). The crayfish were actually impinged in greater numbers when the intake volume was reduced. Helvey (1981) in study of an offshore intake near Redondo Beach, California clearly demonstrated the structure influenced the fish community.

A tidal pattern of capture on sub-littoral intakes with most of the catch occurring around low water is particularly pronounced at localities where there are extensive areas of inter-tidal habitat. A particularly clear example is given by Henderson(1987) in a study of impingement at Hinkley Point Nuclear Power Station which is situated in the lower Severn Estuary, England. This is a high turbidity estuary, the salinity at the intakes is frequently above 30 ‰, and the sub-littoral intake is placed offshore of a 40 km^2 area of inter-tidal mud flat. Some of the most abundant animals, including the common shrimp, *Crangon crangon*, are typically impinged around low water when they have retreated from the inter-tidal towards the sub-tidal intake. Fish such as gobies that also use the littoral show a similar tidal pattern.

Pelagic fish, such as the members of the herring family, tend to avoid coastal littoral zones but frequently aggregate close inshore. Thus they are particularly vulnerable to sub-littoral intakes. In regions where intakes have been positioned on migratory routes or over-wintering grounds very large catches have been recorded. Other migratory fish are also known to move along coasts and into estuaries by following near shore depth contours along the sub-littoral and thus will be particularly vulnerable to sub-littoral intakes. The above considerations explain why offshore, sub-littoral intakes usually catch as many fish as intakes positioned on-shore (See Section 3 below for an example of a study of catch rates at different marine and estuarine localities). The assertion in the proposal which states “the littoral zone is generally the area where aquatic organisms are the most abundant and most susceptible to impingement and entrainment” is not supported by observation.

There is no ecological merit in allowing sub-littoral intakes in the lakes or oceans to be less stringently regulated than those situated in the littoral or in estuaries, and there is significant danger in allowing once-through cooling in sub-littoral areas. We know of no study that indicates that the 50 m buffer EPA proposes outside of the freshwater littoral zones is sufficient to alleviate the potential hazards, and all indications are that significant ecological impairment may occur. There may be areas of coast, well away from estuaries and situated in unproductive waters, where sub-littoral intakes would catch few fish. A possible example from Table 1 is Wylfa Nuclear Power Station; however, this is situated on a rocky, exposed, shore and tends to catch reef living fish that are often territorial and live in smaller populations. Even in such cases, the ecological impact may, therefore, be considerably larger than the smaller (although still considerable) number of impingement moralities suggests.

3 Flow and volume

Effects of volume pumped on fish impingement and entrainment

One of the key aspects that must be considered is the relationship between the number of organisms killed by impingement and entrainment and the location and size of the intake. It is apparent that within a single water body, the larger the volume pumped the larger the number of passively transported planktonic organisms that will be entrained. However, water bodies differ in their ecology and animal abundance and

species differ in their preferred position within a water body, so it can be argued that the locality and position of the intake can have a large effect on the number of fish and other creatures captured. Living animals, particularly the larger fish and crustaceans that are powerful swimmers, do not behave like passive objects and thus their catch rate can vary in a non-proportional manner with the volume of water pumped. As will be shown below there is a clear tendency for catch rates to increase as a power function of the volume of water extracted, but there are some species that behave very differently. Wyman(1984) in a study of impingement at Lake Ontario power plants operating with different numbers of cooling water pumps found that species responded differently. *Alosa pseudoharengus* and *Osmerus mordax* were apparently attracted to the water currents entering the intake and were caught in greater numbers per unit volume as the volume pumped increased. This response has often been observed but is usually explained by increased intake velocities leading to more fish entering a zone where water speed exceeds their sustainable swimming speed. *Morone americana*, *Morone chysops*, *Dorosoma cepedianium* and *Perca flavescens* were caught at a constant rate per unit volume irrespective of flow and *Micropterus dolomieui* were caught in lower numbers per unit volume as flow increased. It was concluded that this latter species avoided faster flowing waters and was thus proportionately more vulnerable to intakes with a reduced pumping rate.

One of the most comprehensive studies of the relationship between the volume of water pumped and the number of freshwater fish impinged and entrained in power station cooling water systems was that undertaken by Kelso(1979) for direct-cooled power plants on the Great Lakes. They analysed entrainment and impingement rates separately. Using data collected from 37 power plants, the number of fish impingement per annum (I) was related to power plant generating output capacity in Megawatts (Mwe) by the regression equation:

$\log_{10}(I) = 0.414 + 1.844 \log_{10}(Mwe)$.

The number of fish entrained per annum (E) was similarly related by the equation:

$\log_{10}(E) = 2.103 + 1.658 \log_{10}(Mwe)$.

From this analysis they concluded that for entrainment: “The ‘harvest’ is apparently influenced more by plant size than location within the great lakes” and impingement: “ in general there is a significant influence exerted by power plant size”.

The output capacity and the rate of water extraction by direct cooled power stations is positively correlated, irrespective of plant design and Kelso(1979) gave the relationship between cooling water extraction rate (C) in m^3s^{-1} and capacity in Megawatts (Mwe) as:

$C = -1.288 + 0.049$ Mwe.

This empirically derived equation obviously cannot be used to extrapolate water usage for plants much smaller than those included in the dataset, as it would predict negative water use. However, it is sufficiently reliable to be used to predict fish impingement and entrainment mortality at the working power stations that were studied.

Combining the above equations and converting water flow to gallons per second (G) the following equations relate impingement and entrainment rates to flow:

$\log_{10}(I) = 0.414 + 1.844 \log_{10}(G+340.25)/12.944)$ and

$\log_{10}(E) = 2.103 + 1.658 \log_{10}(G+340.25)/12.944)$.

Antilogging and simplifying the above equations gives the power curves:

$I = 0.023(G+340.25)^{1.844}$
and

$E = 1.816(G+340.25)^{1.658}$

respectively.

A clear example of the importance of the volume of water extracted on the number of fish impinged is given by Benda (1975) in a study of impingement at the Palisades Nuclear Power Plant, Lake Michigan, while operating with once-through and evaporative cooling tower closed cooling. The volume of water extracted in each mode was 8101 and 1226 gallons s^{-1} respectively. Annual estimates of fish impingement were approximately 452,577 and 7,488 for once through and closed cycle respectively. However, the number of crayfish, *Orconectes propinquis*, actually increased (see above Benda, John et al. 1975).

The relative unimportance of locality when compared with the influence of the volume of water pumped was also found to be the case in a study of marine and estuarine direct-cooled stations. Henderson (1989) reported a study that examined the influence of locality on the rate of fish impingement for British direct-cooled coastal power stations. Quantitative data allowing the estimation of annual impingement was available for 9 power plants over a wide latitudinal and habitat range. The habitats in the vicinity of the intakes varied from upper estuarine to exposed coastal sites with offshore intakes. The results presented are summarised in Table 1. It was concluded that while the annual catch varied between stations by about two orders of magnitude, the catch of all species other than sprat (a shoaling clupeid), standardised for water volume pumped, was remarkably similar at between 1 and 5.8×10^5 individuals per annum per 30 m^3s^{-1}. Given the large between year variation in catches and the widely different sampling efforts used at each locality this suggests no appreciable difference in overall catch rate over a wide range of habitats and geographical position. The one exception was Wylfa power station, which was unique to having cooling water intakes in an exposed, rocky shore, habitat. If sprat, *Sprattus sprattus*, which is a clupeid fish that forms extremely large shoals was included, then the between power station catch would have been more variable. This is because stations with intakes on their migratory pathways or over-wintering grounds can occasionally catch extremely large numbers. Some marine direct-cooled power stations have experienced emergency shutdowns because the filter screens became clogged and failed because of the weight of sprat impinged. High temporal and spatial variability in catch rates linked to clupeid (herring family) abundance is also a feature of N. American marine and freshwaters.

Table 1 The total species and annual catch of individual fish at the sampled power station sites. The total excluding sprat and this value standardised to a pumping rate of 30 m3s-1 are also given. N/A indicates that quantitative annual estimates were unavailable.

Power Station	Estimated annual catch	Annual catch less sprat	Standardised catch for a pumping rate of 30 m^3s^{-1} less sprat	Total species number	Freshwater species
Wylfa	0.5×10^5	0.5×10^5	0.25×10^5	59	0
Heysham 'A'	7.6×10^5	5.4×10^5	3.6×10^5	51	0
Berkeley	N/A	N/A	N/A	71	11
Oldbury	2.5×10^5	2.5×10^5	2.8×10^5	75	10
Uskmouth 'B'	N/A	N/A	N/A	35	3
Hinkley 'B'	12.3×10^5	11.0×10^5	7.6×10^5	77	0
Fawley	2.7×10^5	1.7×10^5	1.0×10^5	80	0
Dungeness 'B'	11.4×10^5	6.85×10^5	4.8×10^5	79	0
Kingsnorth	9.9×10^5	9.9×10^5	4.6×10^5	59	5
West Thurrock	2.6×10^5	2.6×10^5	2.06×10^5	68	4
Sizewell	37.3×10^5	6.62×10^5	5.8×10^5	73	0
Blyth	N/A	N/A	N/A	48	0

An interesting feature noted by was that the number of species impinged varied consistently with latitude, with more northerly stations catching markedly fewer fish species. This would be expected, as species diversity is known to generally decrease with increasing latitude. However, while more northern stations caught fewer species they did not catch fewer individuals. This suggested that the average abundance of individuals in the water did not vary consistently with latitude. Productive northern waters had fewer species, but each of these species was part of a larger population. North American data shows a similar pattern with intakes situated in more northern, less species rich waters, still catching large numbers of individuals.

Since the publication of Henderson (1989) considerably more information on impingement on Northeast Atlantic direct-cooled power stations has become available. Table 2 presents estimated annual impingement at 18 coastal power stations ranging in location from Northern France to Northern Ireland. These data were extracted from a wide variety of original reports. As was found for the freshwater fish fauna of the Great Lakes, the rate of fish impingement increases with the volume of water pumped and the relationship can usefully be described by a power function $I = 9 \times 10^{-7} G^{3.055}$ where G is the pumping rate in gallons per second and I is the number of fish impinged per annum. (When calculating this regression data for Wylfa and Torness were not included. The Wylfa data point was omitted because the site is highly atypical (a rocky exposed coastal locality) and Torness because insufficient data was available to give confidence that the annual impingement estimate was correct.)

The mathematical relationship between the number of fish impinged and the volume of water pumped for both the freshwater Great Lakes stations and the North East Atlantic marine and estuarine stations shows a similar mathematical relationship of accelerating rates of impingement with volume that is reasonably described by a power law. The impingement estimates in Table 2 are of similar magnitude to those observed at N. American intakes. For example, Indian Point, 2 & 3 and Roseton which are direct-cooled units on an estuarine site in the Hudson River impinge about

1×10^6 and 1.67×10^5 fish per annum. The above analyses lead to the general conclusion that pumping rate is considerably more important than locality and intake configuration in determining the number of fish either entrained or impinged.

Table 2 Estimated annual fish impingement at marine and estuarine power stations in the North West Atlantic

Power Station	Pumping rate m^3s^{-1}	Pumping rate Gallons per day	Impingement Numbers per annum
Hinkley	30	6.85E+08	9.27E+05
West Thurrock	50	1.14E+09	1.76E+07
Sizewell A	34.2	7.81E+08	3.73E+06
Wylfa	68	1.55E+09	3.98E+04
Fawley	50	1.14E+09	6.00E+05
Oldbury	26.5	6.05E+08	1.76E+06
Heysham	30	6.85E+08	7.70E+05
Dungeness B	42.4	9.68E+08	1.10E+06
Hartlepool	40	9.13E+08	4.82E+06
Kingsnorth	64	1.46E+09	9.93E+05
Torness	50	1.14E+09	2.18E+04
Coolkeeragh	11.5	2.62E+08	1.73E+04
Ballylumford	29.4	6.71E+08	1.04E+05
Kilroot	16.6	3.79E+08	1.11E+05
Belfast West	9.1	2.08E+08	1.51E+04
Graveline	240	5.48E+09	2.16E+08
Dunkerque	21.2	4.84E+08	6.20E+05
Paluel	86	1.96E+09	1.35E+08

The choice of 2 to 30 million gallons per day thresholds

The proposed minimum daily flow of 2 million gallons per day (MGD) at which the regulations begin to apply is considerably smaller than the water volumes used by almost all direct-cooled power plants. As the rate of fish capture is directly related to volume pumped this proposal would ensure that all intakes at which extremely large numbers of fish would be entrained or impinged will be covered by the proposed regulations. A daily flow of 2MGD is sufficiently low, when taken together with limitations on the proportion of the volume of the source water that can be extracted, to ensure that all intakes likely to have an appreciable impact on the populations of aquatic life are included. However, there is no minimum flow that can be defined at which intakes can be designed to eliminate impingement and entrainment mortality. Given, for example, the flow-catch relationship found for the Great Lakes power plants by Kelso(1979), a 2 MGD intake would be predicted to result in 31,926 and 1,215 entrainment and impingement fish captures per annum respectively. Planktonic organisms will be caught by even the smallest intake as is apparent given the use by biologists of pump samplers which will only remove a few hundred gallons of water per sample.

At the top end of the proposed thresholds, a 30 MGD intake if poorly sited in a sensitive ecosystem has the potential to kill large numbers of entrained organisms.

The young stages of fish and other planktonic organisms can be highly aggregated and thus large moralities could be produced by a poorly designed cooling water system. Aston & Fleming (1992) report a study of entrainment of juvenile fish at riverine British power plants with evaporative cooling towers or low flows. The results presented in Table 3 below show that Didcot Power Station, with an evaporative cooling tower system and an intake flow of 27.9 MGD caught 12,418 juvenile, many cypinid, fish per day. Aston & Fleming (1992) considered that the reason why no juveniles were entrained at Ironbridge was linked to the positioning of the intakes in waters not used by juveniles.

Table 3 Entrainment of juvenile fish at British power stations on rivers with low intake flows.

Power station	Intake flow MGD	Entrainment rate, numbers per day
Staythorpe B	220	50,828
Castle Donington	43	1,792
Ironbridge	15.8	0
Didcot	27.9	12,418

Flow restrictions based on size of source waterbodies

For flowing freshwaters it is proposed that the maximum intake flow be the minimum of 5% of the average annual flow or 25% of the stream 7Q10. The EPA estimates that this proposal taken in conjunction with other constraints will result in protection of greater than 99% of the aquatic fauna. EPA does not support this claim, and the number of animals killed would depend on the distribution and behaviour of the organisms as well as the flow withdrawn and the variation in river flow.

The flow of most US surface waters is highly seasonal and varies considerably between years so it is likely that the 7Q10 minimum constraint will often determine the upper limit for extraction. In drought years this constraint would effectively allow a reduction in the level of environmental protection over that offered in more typical periods. Over the usual life of a power plant of 40 years or more it is likely that there will be periods when flow is lower than the 7Q10 and thus, for short periods, even more than 25% of the flow could be removed. The problem from the ecological viewpoint with this proposal is that during extreme droughts, when the aquatic life is already stressed, the impact from water extraction (and discharge) would be particularly high. This could result in considerable ecological damage from which it might take the river fauna a number of years to recover. Indeed, recovery might not be complete before the next drought occurs so that the net result is a gradual degradation of the fauna. The proposal thus offers no guarantees that the 99% level of protection can be achieved, and offers no support for continuing to develop once-through cooling systems.

For long-lived members of the aquatic community and organisms with limited powers of dispersal it may be conditions during periods of drought that determine the long-term suitability of the habitat. A possible way in which the constraint could be made more ecologically meaningful would be to replace the once in 10 years 7 day mean minimum flow by a once in the designed life of the plant 7 day mean flow. Alternatively, and far more protective, would be an upper limit on the proportion of the flow that could be extracted irrespective of the flow so that during droughts very

little water could be removed. In many localities this might require the installation of dry cooling or other low water usage technology to ensure continuity of operation.

For static freshwaters, it is not proposed to place any constraint on extracted flow in relation to water body volume. It is argued that these are unnecessary because of design constraints that require water bodies to be large enough to act as cooling ponds. In general, heat is lost from the free surface of a water body, but the ecological impact of an intake will be related in some degree to the volume of the water body. Thus a shallow and deep lakes of similar surface area might be able to dispose of similar amounts of waste heat. However, the ecological impacts of water extraction could be considerably different. The deeper water bodies that normally become stratified are given some protection by the stipulation that their natural stratification must be maintained. However, this proposal is rather poorly defined and may not be as protective as intended. It is not the physical presence of thermal stratification, but the way in which it influences aquatic life that is important. Waters that become stratified tend to have a limited movement of oxygen and nutrients between the upper and lower layers. It is this restricted flux that creates the aquatic conditions that lead to characteristic communities in stratified waters. However, if the intakes are taking water from close to the bed of a lake, modifying it during passage through a cooling water system and discharging at the surface then it is possible to envisage situations where the thermal stratification is maintained but an unnatural nutrient flux is created. This could have a similar net effect on the plankton as a breakdown in stratification. It would possibly be more ecologically meaningful to propose that cooling water systems should not change to an appreciable degree the vertical nutrient and oxygen gradients in a static water body. For shallow lakes and reservoirs it is possible to remove a volume of water sufficient to influence the aquatic community while maintaining cooling capacity. There are indeed known examples where the ecology has been sufficiently altered to even raise concerns about dangers to human health because conditions have been made favourable to unnatural pathogens. For example, an amoeba pathogenic to humans, *Naegleria fowleri*, which causes amoebic meningo-encephalitis has been reported from thermally polluted lakes in both the USA and Europe (Langford 1990). Not only does this suggest an alteration in the ecosystem in favour of heat-loving forms, but their control can be difficult and result in further ecological damage. Finally, as noted, there is no indication that limiting cooling water withdrawal so as to maintain lake stratification or to ensure adequate cooling prevents substantial entrainment or impingement of fish, ichthyoplankton or other aquatic biota.

For tidal rivers and estuaries it is proposed to restrict intake flows to no greater than 1% of the volume of the water column in the area centred about the intake with a diameter defined by the distance of 1 tidal excursion at the mean low water level. There are a number of features about this proposal that need consideration. First, the regulation, as proposed, does not stipulate the time period over which the flow is measured. Is it the flow over a tidal cycle that must be less than 1% of the estuarine volume over the tidal excursion distance? In 125.83 the Design intake flow is defined as the total volume of water withdrawn over a *specific period*. Without a clear definition of this period the proposed limitation is meaningless. However, the implication is that no more than 1% of the total volume over a tidal excursion of ebb and flood tide can be removed. This is the volume withdrawn over approximately 12.5 hours, or 1.92% per day. It is also worth noting that the proposal is confusing as

it defines tidal excursion in a manner that is different from general usage, so as to double the flow limit it would allow.

Using this assumption we can now consider how lax the proposal is. As an example consider a hypothetical estuary with features similar to the Hudson River. The average current velocity on flood and ebb tides is 0.38 ms^{-1} so that the tidal excursion (as defined in the proposal) is 0.38 x 6 x 3600 x 2 m = 16416 m. Now the average depth is 25 m and the width of the estuary 2000 m so that the total volume of the area proposed is 16416 x 25 x 2000 = 8.2 x 10^8 m^3. Therefore 1% of this volume is 8.2 x 10^6 m^3. We use the complete width of the estuary in this calculation because it is much smaller than 16416 m.

The maximum flow that would be allowed in our hypothetical estuarine intake would be 8.2 x 10^6 x 2.2 x 10^{-5} = 180 m^3 $s^{-1.}$. A once-through cooling water system for a 1000 MW power plant requires about 30 m^3 s^{-1}. If we have understood the proposal correctly, the proposed restriction is effectively no restriction at all. Even if the proposal were for a daily flow of no more than 1% of the tidal excursion volume this would still give an allowed flow of about 90 m^3 s^{-1} which can hardly be considered conservative. Given that flows at estuarine sites cannot exceed that required by a closed cycle system the proposed restrictions would have no meaning for an estuary such as the Hudson.

Given that flows at estuarine sites cannot exceed that required by a closed cycle system the proposed restrictions would have no meaning for an estuary such as the Hudson. The above example is by no means a worse case as our hypothetical Hudson type estuary is far narrower than many and in some situations the volume would be calculated for a half circle are of water centred on a shore intake.

4 Velocity

It is proposed to limit the maximum intake velocity across the intake screens to 0.5 feet per second as a means of reducing impingement and entrainment mortality. Our focus when considering this proposal is the biological relevance of the proposed velocity and its means of calculation. A number of potential problems with the proposal can be identified which will be addressed in turn below.

The proposed maximum intake velocity will be the calculated velocity across the filter screen or at the point of extraction. It is possible to envisage situations where the calculated velocity is considerably different from the maximum velocity that actually occurs. For example, filters can become partially blocked by debris, sediment or fouling organisms so that higher than calculated velocities occur across the available surface. This can occur on designs where screening occurs at the point of water intake using devices such as wedge-wire screens. Even on rotating drum or band screens the fouling by pond and seaweed, leaves and colonial animals can result in higher than predicted velocities across the screen. Tidal and river flows can also result in widely differing flow rates at different parts of an intake structure. In intake designs where the filter screens are situated on land, perhaps hundreds of yards from the water intake point, animals can enter the system and may even live within it for considerable periods. However, they are doomed because they cannot make their way out and the velocity across the filter screen is of little relevance. In such designs the intake can act almost like a pit-fall trap and even animals that can easily swim from the intake may

enter because they do not recognise the danger. One offshore intake in Britain, for example, with intake velocities close to the levels proposed has been observed to catch seals that had to be rescued from the filter screen wells.

For any fish or planktonic organism there are 3 issues that will determine whether it will escape from entering an intake protected by a filter screen for which the mesh size is greater than the minimum dimension of the organism.

1. Detection – It must notice that it is being drawn in. Visibility and the ambient light and other cues such as sound, touch, turbulence and pressure affect detect ability of intakes.
2. Speed – Once the screen has been detected, for an organism with an ability to swim, it must have the speed to escape.
3. Direction – The direction of the intake flow can be critical. For example the flow must be horizontal to allow fish to react. Vertical flows are unnatural for most species and thus they will not react.

The detection of intakes by fish

A variety of cues help fish to detect intakes. They can detect turbulence in the water in the vicinity of the intake. Large-scale turbulence (relative to body size) is recognised by the labyrinthine receptors detecting the movement of the whole body. The lateral line organ detects small-scale turbulence. Large-scale turbulence in tidal waters will tend to be on the down-tide side of the intake whereas most water (and fish) will enter the intake on the up-tide side. Small-scale turbulence is therefore likely to be more important for detection of intakes by fish.

Fish tend to head up into the faster current if they cross a shear line between two currents. This should result in the fish orientating itself away from intakes if it has crossed a shear line. However, there are only shear lines at the edge of the intake area.

Light has an important effect on the ability a fish to detect and orientate with respect to an intake. Fish catches have been shown to increase significantly at night (Grimes 1975; van den Broek 1979). Intakes positioned in high turbidity waters or below the photic zone, frequently do not show diurnal variation in fish catches, but can be particularly lethal to fish. This last observation is important given the proposal to require less stringent levels of protection at sub-littoral intakes, which by definition are in areas of low light.

Swimming speed and intake velocity

There are two common measures of fish swimming speed, burst speed and maximum sustainable swimming speed. Burst speed is produced by white muscle and creates an anaerobic debt. This debt is costly to the fish and can take 24 hours to repay (Batty & Wardle, 1979). Sustainable swimming speed is produced by the red muscle and is maintainable by the fish for extended periods of time without any oxygen debt.

Although many fish have the ability to out-swim the flows found in and close to intakes, it is far from clear that a fish will escape from an intake using burst swimming. Evidence suggests that they will use steady sustained swimming speeds (Turnpenny 1983). Behaviour in front of intakes appears to be similar to the behaviour in front of trawls (Blaxter and Parrish 1966; Turnpenny 1983), where fish can be observed swimming steadily in front of the mouth of the net but not escaping

it. The fish have the ability to escape but do not as the right stimuli are not present. When the stimuli are applied (i.e. a diver trying to catch the fish by hand) the fish uses its burst speed and easily leaves the net mouth. This tendency to hold station in front of a net or intake can have an impact on the local ecology as intakes are frequently used as hunting grounds by large predatory fish and occasionally birds which find it easy to take steadily swimming, but static, little fish.

Species vary in the proportion of red and white muscle mass present, and this can be used to make general predictions about performance. There are four main groups. Pelagic fish - the fastest swimmers and this group includes Scombrids and Clupeids (herrings). Proximo-benthic fish – modest swimmers this group including the codfishes and flatfish. Benthic species – a group which have no sustained swimming speed and includes gobies, blennies, pipefish and clingfish. Finally anadromous species – these fish tend to be good swimmers as required by their protracted migrations, examples include salmon and shads. It is interesting to note that, despite their swimming performance, pelagic fish are frequently the most abundant forms entrained and impinged. In contrast, benthic fish, particularly forms such as the clingfishes, which have no sustainable swimming ability are rarely caught. Evidently, swimming speed alone does not ensure escape or avoidance.

Within a species swimming speed can be influenced by a number of factors including physiological condition, size and water quality. Amongst adults, speed varies proportionately to body length. This relationship does not hold over the complete size range of a species; small fish can generally swim at a higher number of body lengths per unit time than the adult. Brett (1964) showed that the oxygen requirement of the pacific salmon increase logarithmically over the temperature range of 5-15ºC after which the sustained swimming speed started to reduce as oxygen limitation came into play. Similarly, Turnpenny (1983) found that temperature and body size also affected the sand smelt sustained swimming speed. Thus, swimming speed can vary seasonally and has been used to explain the frequently observed fact that more fish are impinged during the winter. In very cold winters it is possible that an intake that fish are normally easily fast enough to avoid may become lethal.

Direction and the flow characteristics of the screen.

If the flow entering a screen is not perpendicular to the screen it can affect the ability of the fish to escape. Arnold (1974) found that fish orientate at 90 degrees to the screen even when the flow is coming from a different angle. This will have the effect of reducing the effective sustained swimming speed of the fish. Therefore, design velocities for fish escape should be computed as the velocity vector normal to the bars of an intake and not along the streamline.

In canalised intakes, the speed of the water can be higher in restricted parts of the canal than at the coarse screens. This can lead to fish becoming impinged after tiring themselves in the faster canal area before encountering velocities at the coarse screens that they should have been able to escape.

Flows which are not horizontal are much more difficult for fish to deal with. Capping of intakes to cause the flows to become more horizontal have been shown to reduce screen catches. During the early life of Dungeness B, on the south coast of the UK, a comparison of the capture rates of the A and B station were made (Spencer and

Fleming 1987). While the two stations use the same intake structure, the B station has a velocity cap fitted. It was found that the B station catch was reduced by 62% when compared with that of the A (Table 4). This large decrease was largely due to the reduction in sprat impingement.

Table 4 The number of fish caught at Dungeness A and B during one years sampling 24hr samples on 1 filter screen at each station. (10 months used)

	Dungeness A	Dungeness B	% Decrease
No. of fish caught	88428	32813	62

There were some problems with this study as three cooling water pumps were running at the A station and only one at the B station. The increase in fish impingement when all four pumps of the B station are running is unlikely to be linearly related to volume pumped and thus the velocity cap may not be as advantageous as these observations suggest. Factors including the velocity around the intake, fish swimming speeds and turbulence effects would come into play. The effects of tides and currents on intakes flows are significant. As the tide or current reaches its maximum rate the flow is often at its least normal to the intake structure and leads to higher catches. Such currents also often cause high peak flows in certain areas of the intake.

Which fish cannot sustain 0.5 feet per second?

The above observations make it clear that it is impossible to define with any precision a particular intake velocity that gives effective protection to all fish. We now go on to consider if 0.5 ft per second is a reasonable value. Table 5 shows the experimentally obtained maximum cooling water intake velocities at which fish of different species and age can escape (Turnpenny 1988). The results were calculated for different water temperatures. The figures in bold in Table 5 are below the suggested maximum velocity of 0.5 feet per second. It is notable that the majority of species as young-of-year (O group) are unable to sustain 0.5 feet per second at temperatures around 2.5 °C. This suggests that the swimming speed maximum value would be too high for many North American waters during the winter. It might be more appropriate to develop a maximum intake velocity criterion that included temperature and possibly oxygen also.

As entrainment of larval fish is of particular concern the ability of larval fish to escape from intake water streams is of particular interest. Table 6 gives the highest escape speeds for the larvae of herring, cod and flounder. It can be seen that no post-yolksac larvae are able to achieve even a burst speed of 0.5 fts-1.

Table 5 The maximum approach velocities that will enable fish to escape at different water temperatures. (Turnpenny 1988)

	Age Group O and older				Min Length	Age Group 1 and older			
Temp °C	2.5	7.5	12.5	17.5	Age 1	2.5	7.5	12.5	17.5
Species		ft s^{-1}			inches		ft s^{-1}		
Sprat	0.984	1.313	1.64	1.968	3.15	1.64	2.099	2.559	3.018
Herring	0.984	1.313	1.64	1.968	4.72	1.64	2.133	2.625	3.084
Cod	**0.492**	0.984	1.313	1.805	5.91	0.984	1.706	2.428	3.117
Whiting	**0.328**	0.82	1.313	1.64	5.91	1.148	1.804	2.592	3.346
Pout	**0.262**	**0.492**	0.656	0.951	7.87	1.115	1.968	2.723	3.445
Poor Cod	**0.328**	0.82	1.148	1.64	3.94	0.853	1.313	1.936	2.395
Plaice	**0.262**	**0.492**	0.656	0.984	3.15	0.919	1.575	2.198	3.018
Flounder	**0.328**	0.656	0.984	1.313	4.72	0.919	1.509	2.165	2.822
Dab	**0.066**	**0.328**	0.656	0.853	3.94	**0.394**	0.755	**0.115**	1.509
Sole	**0.164**	**0.492**	0.656	0.984	4.33	0.722	1.313	1.87	2.362
Bass	0.656	1.148	1.64	2.165	3.54	1.214	1.937	2.725	3.578
Grey Mullets	0.656	1.148	1.64	1.968	3.94	0.984	1.64	2.265	2.922
Sand Smelt	**0.328**	0.656	0.984	1.313	2.76	0.788	1.313	1.74	2.297
	Age Group 1 and older					Age Group 2 and older			
Salmon Smolts	1.476	1.968	2.297	2.625	5.91	1.804	2.231	2.592	2.986

Table 6 *Clupea harengus, Gadus morhua* and *Platichthys flesus*. Highest escape speeds (ft s^{-1}) during starvation (BL s^{-1} given in parentheses). Speeds are means ± 95% confidence limits (Converted from (Yin and Blaxter 1987)).

	Probe		Pipette	
	max	mean	max	mean
Yolk-sac larvae				
Clyde herring	0.443 ± 0.069	0.217 ± 0.062	0.499 ± 0.043	0.24 ± 0.033
	(13.2 ± 2.1)	(6.5 ± 1.9)	(14.9 ± 1.3)	(7.2 ± 1.0)
Baltic herring	0.423 ± 0.039	0.197 ± 0.013	0.456 ± 0.043	0.203 ± 0.033
	(14.9 ± 1.4)	(6.9 ± 0.8)	(16.1 ± 1.5)	(7.5 ± 1.2)
Cod	0.226 ± 0.023	0.118 ± 0.016	0.262 ± 0.026	0.141 ± 0.016
	(13.2 ± 1.3)	(7.2 ± 1.0)	(15.1 ± 1.5)	(8.6 ± 1.0)
Flounder	0.184 ± 0.03	0.098 ± 0.02	0.213 ± 0.049	0.115 ± 0.03
	(13.0 ± 2.1)	(6.9 ± 1.4)	(15.1 ± 3.5)	(8.1 ± 2.1)
Older larvae	Clyde herring			
36 d-old	0.577 ± 0.135	0.269 ± 0.075	0.643 ± 0.079	0.328 ± 0.046
	(12.1 ± 2.8)	(5.7 ± 1.6)	(13.5 ± 1.6)	(6.9 ± 1.0)
60 d-old	0.81 ± 0.161	0.417 ± 0.095	0.84 ± 0.128	0.476 ± 0.049
	(13.0 ± 2.6)	(6.7 ± 1.5)	(13.5 ± 2.0)	(7.6 ± 0.8)

The situation with respect to larval escape cannot be much improved by reducing intake velocities further because there is little evidence that larvae upon detecting the flow of water will dart in a direction that will ensure their escape. Table 7 shows the number of larvae of herring, cod and flounder that moved away (A), towards (T) or in some other direction (A/T) when stimulated by a sudden flow of water. As can be seen, a considerable proportion actually moved towards the point at which water was being withdrawn.

Table 7 *Clupea harengus, Gadus morhua* and *Platichthys flesus*. Numbers of larvae turning away from (A), towards (T) and aligned with (A/T) a point of stimulation (probe or pipette) during early development (Yin and Blaxter 1987).

	Probe				Pipette		
	A	T	A/T		A	T	A/T
Clyde Herring	57	31	16		108	63	46
Baltic Herring	42	18	5		89	34	17
Cod	69	33	10		72	31	16
Flounder	37	25	30		48	26	21
Total	205	107	61		317	154	100
Percent	54.95979	28.68633	16.35389		55.51664	26.97023	17.51313
	Away	Not Away			Away	Not Away	
Total	205	168			317	254	
Percent	54.95979	45.04021			55.51664	44.48336	

A summary of the problems with the 0.5 feet per second criterion

1. Fish often do not know in which way to swim and so may become entrained or impinged even if they have the speed to escape.
2. There is no mention of the direction of flow relative to gravity; horizontal flows are less dangerous than vertical flows. (Intake capping is mentioned as a possible remedial measure).
3. There is no consideration of the effect of tide, currents etc. on flow rates though screens.
4. There can be problems because fish orientate at 90 degrees to the screens not the flow.
5. The velocity is determined at the screens - at this point the fish may already be trapped.
6. Temperature effects are not mentioned - at 2.5 °C most young temperate water fish are unable to sustain 0.5 ft/s.
7. Evidence suggests that the effect of high temperatures might limit oxygen and therefore reduce the sustainable swimming speed of fish.
8. Fish eggs are often free floating and are therefore vulnerable to entrainment irrespective of intake velocity.
9. Larval fish, post-larval fish and very young fish are poor swimmers and many cannot achieve 0.5 ft/sec. They also do not all react to a flow by moving away from it.

5 Additional design and construction technologies

The EPA proposes that facilities with intake structures in the littoral zone implement additional technologies to minimise impingement and entrainment of fish and maximise the survival of impinged fish. No specific technologies are proposed for mandatory use and the proposals are in reality a rather vague list of possible techniques that have been tried, often with limited success, in the past. The idea seems to be to hope that a suitable suite of techniques can be implemented as appropriate at each new site. However, it is unclear how this choice of techniques should be undertaken. We will consider the applicability of the different major classes of technique proposed to greatly reduce fish entrainment and impingement below.

Techniques to maximise survival of impinged fish

These include fish diversion, handling and return systems, each of which will be considered in turn.

A variety of methodologies have been tried to divert fish from entering intakes including, bubble curtains, sound barriers, lights, louvers, electric fields and other methods that scare fish away. At best they have been partially successful and are almost inevitably somewhat species specific in their effectiveness. At worst, they can actually increase the catch of some fish. For example, a sound deterrent system installed at Hinkley Point B Power Station had the effect of increasing the impingement of sprat (a small member of the herring family). This was possibly because when the fish heard the sound their natural fright reaction was to dive downwards, which resulted in them moving towards the intake. Tests with lights and bubble curtains have frequently found them to be almost totally ineffective. Perhaps, the most effective diversion device for rivers is a louver screen system. However, even these can only be partially successful and will not divert larval and weakly swimming fish.

Fish handling and return systems include pumps, lifts and sluicing systems and are best viewed as rescue methods of last resort to save impinged fish. They can never be completely effective as impinged fish suffer damage when they come into contact with surfaces, particularly the filter screens, and they are often disorientated and exhausted and thus may not recover when returned to their native water. Damage following contact with surfaces is particularly severe for clupeids and pelagic fish in general, which are by far the most abundant group of fish impinged on power station intakes. They often suffer scale loss and subsequently die due to exhaustion and osmotic shock.

Technologies that minimise fish impingement and entrainment

Two major technologies are suggested as mitigation methods, Gunderbooms and similar fine screens, and passive intake structures such as wedge wire screens. The applicability of each will be considered in turn.

<u>The Gunderboom as an entrainment mitigation device.</u>

The Gunderboom is constructed from a fine mesh material that can potentially be deployed as a curtain or a series of panels around an intake. Since 1995 a Gunderboom has been tested at the Lovett generating station on the Hudson River at

Tompkins Cove, NY. The basic idea is to surround the intake in a large surface area of fine filter material through which the cooling water will pass at a low velocity. Ichthyoplankton will not pass across the barrier. The only information on which to base the applicability of the Gunderboom technology are the reports arising from the experimental deployment at Lovett. In laboratory and short-term field trials there can be no doubt that a Gunderboom can reduce fish entrainment. However, as will be described below we have considerable reservations as to the longer-term utility of this technology. At present, it is best considered a technology that might be applicable in particular, specialist circumstances.

A Gunderboom for even a quite small cooling water intake requires a large surface area, which is resistant to flow and is vulnerable to physical damage. They would therefore be unlikely to be deployable in exposed marine or lower estuarine sites where there is powerful wave action or strong currents or water flows. The dragging of the anchors, over-topping of the boom and a rupture in the filter material, which were all experienced at Lovett, are typical of the types of operating problems that would be expected. Similar problems would be expected in flowing freshwaters that receive storm waters or large lakes with appreciable wave action. Such problems would be anticipated irrespective of whether the filter material was attached to a boom or installed in fixed panels.

The fine pores in the filter screen are highly vulnerable to becoming blocked. At the Lovett experimental deployment, sediment was removed from the filters by the use of an air bubble system. Such a system would be highly unlikely to work in the high turbidity estuarine waters that are found in areas with powerful tides and soft substrates. Further, it was pointed out during the trials that the bubble cleaning system *was unable to remove algae* and other fouling organisms from the filter. From experience with porous tubes used to produce bubble curtains it is known that biofouling is a considerable problem and in many habitats we would anticipate that long-term deployment would result in appreciable blockage of the filter by bacterial, fungal and algal growths leading quickly to filter screen failure.

The Gunderboom was not tested in waters that, during a spring or autumn plankton bloom, can hold appreciable quantities of colonial planktonic algal and bacterial species such as Phaeocystis. These colonial organisms can form a gelatinous slime within which the individual cells live. They can make the use of plankton nets impossible as they quickly block the mesh and a similar effect can be anticipated with a Gunderboom.

If a Gunderboom is to effectively reduce entrainment, it will need to be deployed for a considerable proportion of the year, for in many waters there are few months when eggs, larvae or juveniles of fish are absent. Such a long-term deployment has not yet been attempted and is likely to produce effects that have not been anticipated. It has been demonstrated that a clean filter surface will not lead to the death of eggs and larvae that are pulled against it. However, this may not be the case when the surface is colonised with a fouling community. A community that may come to hold animals that are prospering because they are feeding on small animals pulled onto the surface by the suction.

To summarise, the applicability of Gunderboom technology depends on the ability of the structure to withstand the physical forces to which it will be exposed, forces that will become greater as the filter becomes clogged. The failures experienced at Lovett do not inspire confidence that this can be achieved without unrealistic maintenance schedules. The trials at Lovett noted that the bubble cleaning technology was unable to remove algae from the filter. To afford useful protection to fish and other organisms the filter must be deployed for long periods and must therefore not become excessively fouled and blocked. The establishment of a biofouling community can have two effects. First, it will reduce filter capacity that may result in the failure of the screen. Even if the screen does not fail, there may form small regions with much higher velocities through which eggs and larvae are forced. Second, this community may include a range of predatory or pathogenic organisms that are present because they feed on the eggs and delicate larvae that are pulled towards the surface. Such possibilities have not yet been tested and lead us to conclude that the Gunderboom cannot be considered a tried technology for general use.

Passive systems - wedge wire screens – filter beds etc

Wedge wire screens typically have a 0.5-2.0 mm slot mesh and can almost eliminate juvenile and adult fish deaths on intakes. However, they do not eliminate all entrainment (most planktonic crustaceans, including the larvae of fish, shrimps and crabs plus planktonic algae will be entrained) and they are subject to sedimentation. Wedge wire screens are also vulnerable to biofouling resulting in a decrease in water flow. The use of such passive screen systems cannot be used in all waters because of their large size and the disruption caused to the natural bank and riverbed. To reduce biofouling, wedge wire screens are made that continually leach copper. The introduction of such a toxic compound into the water body may be undesirable.

Methods involving filtration through sand and gravel can certainly be effective, but cannot be used in depositing environments such as lowland rivers. They cannot be viewed as a widely applicable technology.

An example of the planned application of mitigation technology

We are able to obtain some idea of the possible gains that can be made by the application of a suite of fish protection measures by looking at a specific example. At Sizewell on the east coast of the UK a new Pressurised Water Reactor Station has been recently built, based on an American design, alongside an existing station. Sizewell A has been a major catcher of fish over many years, reaching levels sufficient to cause blockages in the cooling water system and station shut-down. The main species impinged is the sprat (*Sprattus sprattus*), a small clupeid. This fish over winters close inshore especially in turbid waters. During the design phase of the B station several changes and improvements were made to the cooling water system to try and reduce the fish catch (Fleming, Seaby et al. 1994) including:

1. Adoption of a capped intake;
2. Adoption of a 50 cm/s designed approach velocity;
3. Location of the sub-littoral intake further offshore;
4. Elimination of intake superstructures;
5. Incorporation of a fish return system.

The intake was capped for two reasons, first to withdraw cooler deeper water and reduce the possibility of the formation of a surface vortex. Second, it allows fish to

respond to horizontal rather than vertical flows. Fish species are ill equipped to deal with vertical flows and this has been shown to be particularly effective in reducing the impingement of pelagic species.

The adoption of a 50 cm/s design approach velocity has a doubtful benefit at Sizewell. The designed approach velocity only applies during slack water. Once the tide starts to flow, the intake water velocity will differ widely on the up and down tide sides of the intake.

The inshore waters around Sizewell are an important nursery ground for flatfish. Moving the intakes from 300m (the position of the A station intakes) to 600m offshore was an attempt to reduce flatfish impingement.

The superstructure of an intake acts as artificial reef. The construction of the intake without a superstructure was designed to reduce the attractiveness of the area to reef dwelling fish.

With all devices present and working the total fish catch at Sizewell B showed an approximately 50% decrease per m^3s^{-1} over the number of fish caught at Sizewell A. For all species, other than sprat, the figures show a 35% decrease (Table 8).

Table 8 Mean daily catch per cumec of water abstracted at Sizewell A and B

	Sizewell A	Sizewell B	% Difference
All Fish Species	168.34	83.98	50.1
All Fish Species (exc. Sprat)	75.44	48.78	35.3

Sizewell B also had a fish return system to return as many as possible of the fish to the sea alive. Analysis of the survivorship of impinged fish indicated that it varied widely from species to species but tends to follow the basic pattern that pelagic species do not survive and the more bottom-living the species, the greater the survival. Species with no swim bladders (i.e. the flatfish) generally survived the fish return system. Species which had un-sealed swim bladders (physotomes) also survived well. Fish species with sealed swim bladders (physoclists) often, upon dissection, were found to have burst swim bladders. During impingement the fish would undergo depth changes, which would change the pressure rapidly from 3 to 1 atmospheres. The net result is that the fish return system while protecting some species did not greatly reduce the total number of individual fish killed by impingement.

In conclusion, at a coastal site with direct cooling the implementation of a full suite of state of the art fish protection features that were purpose built for the station were able to reduce annual fish impingement mortality by about 50%. However, this still results in many millions of animals being killed per year. A final important finding of this study was the importance of pressure changes within the intake system. To improve fish survival the EPA should consider defining the maximum pressure change to which fish are exposed. Pressure changes become much more important when sub-littoral intakes are used as the fish may be rapidly taken into a lower pressure regime. Such intakes can kill physoclist fish even before they are impinged on the screens.

6 Adverse environmental impacts of cooling water impact structures.

Effects at the ecosystem level

The main focus of the EPA proposals is to reduce the direct effects of cooling water intakes on fish impingement and entrainment. However, cooling water intakes affect many components within the local ecosystem and can potentially produce a wide range of impacts many of which are difficult to foresee. Some of these changes can lead to indirect effects on fish, crustaceans and top predators such as birds, as well as decomposers at the bottom end of the ecological hierarchy. Such changes are difficult to detect and document and have been little studied (A comprehensive review of knowledge up to 1983 is given in Langford (1983)). For many localities they have been hidden by other anthropogenic impacts because cooling water intakes have rarely been sited in pristine natural waters in which the local ecology has been studied prior to construction. Some of these indirect effects have been introduced above and will be brought together in this section from an ecosystem viewpoint. At the outset we need to be clear about how we can detect ecosystem level effects rather than changes in individual species populations.

While an individual organism can clearly be observed to respond to stress, it is by no means clear that such a concept can be applied to an ecosystem. It is clear that ecosystems can be damaged by human activities and even completely destroyed, but is it possible to detect changes that demonstrate that they are being placed under stress and ultimately suffering damage? Ulanowicz (1996) argues that ecosystem stress can be defined as an inhibition or reversal of the natural succession as characterised by Odum (1969). The main characteristics of this natural succession can be listed as:

1. Increasing species richness;
2. progressively greater trophic efficiency;
3. a richer structure for recycling materials;
4. more intense system activity;
5. greater trophic specialisation.

At the base of aquatic ecosystems there are the primary producers and the decomposer organisms. The primary producers can be divided between the large plants such as seaweeds and angiosperms which normally are fixed to the substrate and are limited to shallow waters and the terrestrial fringe and the planktonic, often single celled algae, protozoans and bacteria. The decomposers, which are particularly active in the substrate, comprise fungi and bacteria. Energy input into the system is derived from light and autochthonous material such as leaves and wood and human waste which is often terrestrial in origin. Both the primary producers and decomposers are used as food by a wide range of organisms. In the plankton, small crustaceans such as copepods are particularly important. A wide range of benthic worms, insects and filter feeders consume the decomposers. These primary consumers are fed on by small predators such fish, insects and larger crustaceans that are in turn the food for large fish, mammals and birds.

This general scheme is found in all shallow waters and is highly adaptable in that the relative size and ecological activity of the different components can change

dramatically between localities. In some areas, with large allochthonous inputs, the decomposers can dominate while in other waters the planktonic primary producers may be the dominate the base of the food web. The presence of a cooling water intake can influence the relative size and economy of the different components within an aquatic ecosystem. The general routes by which a cooling water system may stress the local ecosystem are as follows:

1. Differential mortality of different species resulting in changes in competitive ability.
2. The destruction of primary producers resulting in reduced production.
3. The destruction of planktonic primary consumers resulting in impoverished plankton.
4. Destruction of prey for juvenile fish, resulting in decreased food supply for various life stages of fish
5. The release of large numbers of dead planktonic organisms with the discharge water resulting in an enhanced energy input into the decomposer system.
6. Changes in the temperature, oxygen concentration and other physical variables that change the rate of ecological activity and relative competitive advantage between species.
7. The alteration of flow regimes and associated physical variables such as sediments that can result in a shift in species composition.
8. The creation of fixed structures that can act as reefs and change the species composition.
9. The introduction of large areas of hard surface on intake pipes, docks, cooling tower slats and other structures that can be colonised by organisms not normally abundant in the system.
10. The displacement of organisms, materials and nutrients from around the intake to the area of discharge resulting in the establishment of a non-equilibrium or unusual community in the discharge area.

This list is by no means complete, but it gives a feel for the wide range of channels via which a cooling water system impacts the local aquatic ecology. One means by which the impact of a power station can be appreciated is to visualise it as a giant, non-selective, filter feeder. It is rather like a whale that filters water and excretes to its environment and offers a habitat to a wide gut flora and a skin that is colonised by barnacles and other parasitic organisms. Fish and other predators can be attracted to the vicinity of the whale because it stirs up the water and sediments and places their prey in exposed positions where thy can easily be attacked. When it is argued that cooling water intakes are having no impact it is worth considering if it would seriously be suggested that a group of giant whales could be added to the same water body without appreciable impact.

However, this analogy may significantly understate the impact of cooling intakes. The whale moves and can seek out the richest feeding waters whereas cooling water intakes are static and thus tend to focus their impact on a restricted area. In tidal and flowing waters the movement of the water results in a large-scale impact on the plankton and active swimming community that is not dissimilar to what would be achieved by a mobile intake.

Many of the arguments claiming that power plants have negligible effects are based on the concept of surplus production. From an ecosystem perspective there can never be surplus production that can be removed from any component without impacting other parts of the system. It is self-evident that without the cooling water intake, other organisms would have consumed the production taken by the station (Boreman 2000).

A recent and unusual example of the effect of a power plant at the ecosystem level is the study by Ulanowicz (1996) on creeks subject to discharges from a nuclear power station on the Crystal River, Florida. He noted that the greatest impact of the power station was on the highest trophic levels where the top predators, gulf flounder and stingray, either disappeared or changed their feeding pattern. There was clear evidence that the stressed system had reduced transfer efficiencies of energy from the lower to higher trophic levels. There was also a marked change in material recycling between stressed and natural creeks with faster recycling in the stressed system because material was retained at the lower trophic levels.

We know of no other studies that have attempted such a quantitative analysis of an ecosystem under stress from a power plant. However, there are considerable amounts of evidence indicating such aquatic ecosystem stress, typically reflected in a loss of top predators and a change in detrital and other low trophic levels concerned with recycling. The loss of top predators can be anticipated because of the efficiency of transference of production along food chains. This can be illustrated by a simple hypothetical example. A food chain in a pelagic system may comprise the following 4 components: 1. Primary producers – 2. Planktonic crustaceans – 3. Larval fish – 4. Predatory fish. Such a system is impacted most heavily by a cooling water intake via entrainment losses on the first 3 trophic levels. Each of these levels is affected both by the direct loss of individuals and also in the case of levels 2 to 4 by the reduced availability of food. A feature of all such trophic chains is that only a small part of the production at each trophic level is passed to the next highest level and the result is relatively small flows to the top predators. For example, if a 10% transference efficiency is achieved, 1 g of carbon fixed by the primary producers would be transformed into 0.1, 0.01 and 0.001 g of carbon at the planktonic crustacean, larval fish and predatory fish levels respectively. If entrainment results in a reduction in standing crop sufficient to reduce transference efficiencies to 9% then the amount of production at the higher levels is reduced to 0.09, 0.0081 and 0.00073 g of carbon. Thus a 1 % change in efficiency along the chain results in a 27% reduction of production at the predatory fish level. In general, at a large volume intake, stress on the ecosystem can be anticipated to produce just the types of impact noted by Ulanowicz (1996).

In reality, trophic structure is far more complex and species will be impacted to varying degrees. In general, longer-lived slower growing species will tend to be more heavily impacted. These species may be replaced by faster growing competitors. Such changes are characteristic of disturbed systems and generally result in reduced species richness and the efficiency of energy assimilation. While the outcome for particular species may be unpredictable, the essential feature remains: cooling water intakes entrain organisms over the full range of feeding behaviour from autrotroph to top predator. Because they kill organisms at many trophic levels their impact is similar to a general reduction in productivity and efficiency of energy transfer the effects of which will be far greater towards the top of the food web.

From this perspective we can take a radically altered view of some oft-repeated arguments. For example, it has long been argued that entrainment losses of predatory fish, such as striped bass, were acceptable because density-dependent mortality was acting so that the fish would not have survived. If the effect of large-scale once through cooling is to reduce production and energy transference, then density-dependent mortality could be viewed as the end result of a food shortage and thus an indirect effect of entrainment at lower trophic levels.

The above discussion has focussed on energy flux along food chains. Planktonic plants, crustaceans and larval fish are particularly vulnerable to entrainment and can be killed to large numbers. Their loss results in an increased flux of resources to the decomposers (some of which is also derived from dead pieces of larger organisms broken-up by the cooling water system). The net result of reduced energy flux to the top predators and increased decomposer activity is an ecosystem dominated by simpler organisms. Notably, this promotion of decomposer forage at the expense of higher consumers is characteristic of the ecological stresses which in large part prompted the 1972 Clean Water Act amendments.

Other impacts

Evaporative cooling towers carry some potential for localised impact apart from their extraction of cooling water, because they may discharge bacterial slimes, fungi and a variety of organisms which colonise the tower but are not otherwise native to the local ecosystem. Such organisms can be suppressed by the use of biocides that may be discharged with the effluent. Evaporative towers also may concentrate nutrients such as phosphates and, when brackish or marine water is used, discharge salt spray drift. Nonetheless, the potential for localised impact from evaporative towers is relatively minor compared with the substantial improvement in entrainment and impingement over once through cooling, as well as the elimination of thermal impacts.

Aquatic impacts from dry cooled stations are negligible and few environmental problems have been reported. The only adverse impact we are aware of was fungal growth on dead insects in dry cooling tower filters resulting in the release of spores that produced lung irritation; a problem that can be controlled by good maintenance. It is clear that such unanticipated problems are rare and may be monitored and controlled when necessary.

7 The best technology available to minimise adverse environmental impact

It is impossible to remove any significant volume of water from a lake, reservoir, river or the ocean without also removing some of the organisms that are living within it. When water is extracted from healthy natural waters, to an over-riding degree the number of organisms killed be they fish, crustaceans or members of the plankton increases with the volume of water pumped. While much emphasis is placed in the EPA proposals on locality as a determinant of the number of fish killed, it is secondary to the volume of water pumped. Direct cooled power stations use such large volumes of water that there is no available suite of technologies that can be used

to ensure that fish deaths and the impact on other aquatic life can be reduced to the levels that are achievable with the less consumptive forms of closed cycle cooling.

Examples such as the work at San Onofre and Sizewell Nuclear Generating Stations which are discussed in Section 2 support the contention that power plants using once through cooling will kill large numbers of fish by impingement even when considerable effort is expended on the siting of the intake and the installation of fish return technologies. This is principally because clupeids and other pelagic fish are easily damaged when they come into contact with surfaces. Further there is no demonstrated technology that can reduce entrainment at such sites. Moreover, at typical ocean sites antifouling procedures such as chlorination or heat treatment must be used which further pollute and damage the ecosystem. We conclude that once-through cooling is too damaging to inshore ocean ecosystems to be considered the best technology available.

In estuarine and inland waters entrainment is probably the greatest cause of death to aquatic organisms and ecosystem impact. Gunderboom technology has offered the prospect of enhanced protection to fish eggs and larvae at intakes, however, this technology must be viewed as untested and there are considerable doubts as to its applicability in many waters. While fine mesh screens can reduce impingement mortality they offer little reduction in entrainment of plankton. For lakes and rivers once-through cooling, even with sub-littoral intakes and fish protection devices, does not offer equivalent levels of environmental protection to that afforded by dry cooling. Given available alternatives, once-through cooling system in freshwaters are so consumptive as to eliminate serious consideration of them as the best technology available to minimize impact.

Technologies to reduce impingement and entrainment become more practical when closed-cycle cooling is used. The volume extracted by evaporative cooling-tower systems is much smaller than that of a direct-cooled station of similar size. Accordingly, the reduced water requirements can be met from more carefully screened and protected intakes. However, it is impossible to set an extraction volume or flow rate that will reduce the impact to negligible levels and studies have demonstrated that such systems will entrain juvenile fish (e.g. Aston and Fleming 1992). While appropriate technologies exist to almost eliminate the impingement of juvenile and adult fish, entrainment of plankton is almost impossible to stop. When deployed for short periods Gunderbooms are able to stop almost all fish entrainment, but their reliability and ability to work over long time periods and in a variety of waters is untested and open to serious doubt. The introduction of large structures into a water body inevitably changes the local ecology and offers the potential to change the local community.

Evaporative cooling towers extract far less water than once-through cooling systems and thus certainly result in much lower impingement and entrainment mortality. If the aim is to ensure the minimisation of adverse impact on the environment then it is clear that the volume of water extracted from and returned to the natural environment should be minimised. There is a strong argument against the use of once-through cooling in power stations in all environments including oceanic waters. Where dry cooling systems are feasible from an engineering and economic viewpoint, then they

must be the best available technology for the disposal of heat while minimising environmental impact.

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9 Attachment A

Pisces Conservation Ltd
Pisces Conservation Ltd was initially formed from scientists who met while working for the Central Electricity Research Laboratories in England. Key members of staff have worked for more than 30 years on power plant effects in many parts of the world. Dr Peter Henderson has worked for more than 20 years on the ecological modelling of power station impingement and entrainment. He was a director of Fawley Aquatic Research Laboratories and more recently a lecturer at the University of Oxford. He is a co-author of the well known ecological textbook Ecological Methods. Mr Terry Langford was at different times the head of both the Central Electricity Generating Board freshwater and marine laboratories. In a career spanning more than 35 years he has written two books on the effects electricity generation and thermal discharges. Over this entire period he has continued to follow the impacts of freshwater cooling systems. Dr Richard Seaby was trained as a freshwater biologist and has worked for 10 years on the entrainment and impingement of animals on cooling water intakes and fish survival following passage through cooling water circuits and fish return systems. Mr J. Fleming has worked on impingement and entrainment since the early 1960s when he commenced work on the effects of the first commercial nuclear power stations

Authors curricula vitae

Dr Peter Alan Henderson

17 Hursley Drive, Blackfield, Southampton, Hants. SO45, 1ZU
e-mail Henderson@peterah.demon.co.uk

ACADEMIC QUALIFICATIONS

BSc 1st Class Honours Zoology and Applied Entomology: Imperial College, London.

PhD, DIC, University of London, Thesis :- *Population Studies and Behaviour of Cypridopsis vidua (Muller), (Crustacea, Ostracoda)*

PROFESSIONAL HISTORY

Present position. Director PISCES Conservation Ltd.

Employer : Department of Zoology, University of Oxford.
Position : Research Associate and lecturer(1994-1999).

Lecturing on ecological methods and population dynamics. Research undertaken on; (1) the limnology of Amazonian floodplain systems with particular emphasis on micro crustaceans and floating meadow fish communities and population; (2) Population dynamics of fish and crustaceans the Bristol Channel; (3) Population and community dynamics theory with Professor W. D. Hamilton. During my time at Oxford I also completed a revision of the standard textbook Ecological Methods with Professor Sir Richard Southwood.

Employer Projeto Mamiraua
Position Fisheries and Aquatic ecology consultant (1989-1997)
Responsible for management and creation of the initial research and development plan for the reserve and subsequent research on biodiversity.

Employer : Fawley Aquatic Research Laboratories Ltd.
Position : Director (1991-1994)
Responsible for software development, mathematical modeling, statistics and marine and estuarine impact assessments of power stations.

Employer : Central Electricity Research Laboratory and National Power PLC
Position : Research Scientist (1978-1991).
Working on the development of mathematical models of natural systems. Major research areas were (i) population biology of marine fish and crustaceans: (ii) the modeling of water movement: (iii) the causes of red tides: (iv) freshwater community structure in relation to water chemistry changes caused by acid rain.

Other Positions Held

1998- Council of the Fisheries Society of the British Isles.
1984-1990. Assistant editor of the Journal of Fish Biology
1987 - Director of Biological Computing Systems Ltd.
1987-1990 Council of the Linnean Society.
1988 - Associate with John Grimes Partnership - consulting engineers.
1985 -Visiting research fellow for the International Atomic Research Agency.
1983- Research professor for BIDS project Brazil.

Expertise

An ecological consultant and research scientist combining theoretical studies and field biology with 25 years experience. Extensive experience of the management of major ecological assessment projects including preparation and presentation of material for public enquires and liasing with conservation bodies and engineers. Trained and experienced manager of ecological survey and research staff. Recent projects include conservation planning for large tropical reserves, ecological effects studies of nuclear power station intakes and conservation studies of rare animals in small ponds in the New Forest. Lecturer at the University of Oxford and King Alfred College, Winchester. Author with Sir Richard Southwood of tbe new edition of the standard textbook Ecological Methods. Main areas of expertise are itemised below.
a) **Industrial ecology.** Experience gained in power plant engineering including the preparation and presentation of evidence at public inquires and the writing of environmental impact assessments. Project management of major environmental impact studies including Sizewell B, Hinkley C and Fawley B power stations, the Severn tidal barrage scheme and the Usk barrage.
b) **Tropical ecology**. Fisheries manager and ODA consultant on fisheries and aquatic ecosystems for Project Mamiraua in the upper Amazon. Tropical research has been varied and includes work on the taxonomy of Amazonian fish, behaviour of electric eels and the community structure found around leaf litter and floating meadow habitats.
c) **British estuarine and riverine communities**. More than 20 years of study of British estuarine fish and crustacean population dynamics. Studies undertaken of community dynamics, wood webs, climatic effects and predator-prey interactions.
d) **Conservation management planning**. Wide range of projects undertaken including a senoir role in the planning of one of the world's major freshwater reserves, the Mamirauá reserve in Brazil. Responsible for the development of the aquatic strategic management plan for an area of 1,124,000 ha of Amazonian flooded forest holding diverse habitats including lakes, varzea forest, rivers, stream and

floating meadows. The project has developed many novel ways of conserving fish and other aquatic species and is recognised as one of the great success stories of international conservation.
e) **Invertebrate taxonomy**. Author of the Freshwater Ostracods book in the series Synopsis of the British Fauna series. Taxonomic studies also undertaken on mysids, shrimps and fish.
f) **Biological Computer Software**. The designer and developer of computer based expert systems in Windows and DOS, including the commercial software packages E3 (for environmental effects evaluation which is available from The Stationary Office), Species Richness and Diversity (available from PISCES), The Community Analysis Package (available from PISCES) and Dynamica (available from Chapman & Hall).
g) **Population biology**, including the study of fish, ostracod, crustacean and insect populations in many diverse habitats.
h) **Experienced supervisor** of post-graduate students. Lecturer and tutor on the climatic change masters coarse at the University of Oxford.
i) **Writing and broadcasting**. Freelance writer for British Wildlife and other magazines. Currently working as a scientific advisor for the BBC Natural History Unit. Lecturer to natural history clubs and societies on rain forests and British Wildlife.

C. EXTERNAL PUBLICATIONS

Books

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Dr Richard Miles Harrington Seaby

30 Grebe close, Milford on Sea, SO41 0XA,UK
e-mail richard@irchouse.demon.co.uk

EDUCATIONAL QUALIFICATIONS

Ph.D. Aquatic Ecology (1988-1992). University of Liverpool
Thesis : - *Coexistence of Lake-Dwelling Triclads and Leeches.*

B.Sc. 2:1 Hons Biology (1984-1987). Goldsmiths college, University of London.

EMPLOYMENT HISTORY

Employer : PISCES Conservation Ltd.
Position : Managing Director (1995-).

Areas of expertise :

a) **Entrainment and Impingement Effects.** Laboratory and field investigations into the effects of industrial intakes in both marine and freshwaters. Long term power station monitoring projects. Development of PISCES expert system for the prediction of impingement effects of intakes. Evaluation and advice on fish return systems.
b) **Environmental impact assessment**. Projects include: fish tagging and movement in relation to seismic surveys, literature reviews, assessment of effects of seismic surveys on the fish and fisheries in Weymouth Bay, the aquatic effects of a road development in Merseyside, the effects of groundwater pumping on a saltmarsh during gravel extraction. An assessment of the amount and quality of aquatic habitat in a nature reserve in the North of the New Forest.
c) **Population dynamics**. Projects include: long-term sampling programme of fish and crustacean in the Severn Estuary, salmonid population dynamics,. development of a salmon migration model for EA (southern region),
d) **Experimental assessment of environmental stressors**. Evaluation of a Fish Return System at Sizewell power station, The effects of entrainment on fish eggs and larvae
e) **Biological Computer Software**. Developing computer based expert systems in Windows including the commercial software packages E3 (for environmental effects evaluation), Dynamica, Species Diversity and Richness II, Community Analysis Package, Simply Growth, Removal Sampling, Density from Distance and Simply Tagging.

Previous employment

Employer : Fawley Aquatic Research Laboratories Ltd.
Position : Ecologist (1992-1995).

Employer : Liverpool Museum
Position : Demonstrator in natural history centre (1990-92)

RELEVANT PROJECTS

Recent contracts

Survivorship trial of the Fish-return system at Sizewell 'B' Power Station
Project management of a study of the efficiency of fish return systems at Sizewell B Nuclear Power Station. The work was undertaken for Nuclear Electric Plc.

Long term population studies in the Severn Estuary
I have been involved with this study for 6 of its 16 years. This project has become particularly important in recent years with the Estuary becoming a special area of conservation (SAC). This work has involved liasing with MAFF, English Nature, WWF, EA and Nuclear Electric. This work has produced a dataset that is now regarded as internationally important in the understanding of fish populations.

The effect of water abstraction on the Salmon Migration in the River Itchen
As part of ongoing work on the effects of water extraction on the movement of salmon I, with others in PISCES, have produces several report for the NRA and latterly EA. This work has included creating Marcov chain models for the movement of fish from the estuary to the river and analysis of the transfer probabilities of the salmon in relation to flow.

Weymouth bay: fish and fisheries review.
A review of the economic and social importance of the fisheries in Weymouth Bay. This project involved liaison with MAFF, Southern Sea Fisheries and local fishing organisations.

Report on Water Quality in the Keyhaven Reserve
Water quality data for Keyhaven stream and two other small streams flowing into Keyhaven reserve indicated that these streams were receiving ground water inputs. As this water was derived from a gravel pit in the vicinity of a rubbish dump, there were a high risks that Keyhaven pond was receiving elevated heavy metal inputs. This threat to the reserve and the problem of a reduction in dissolved oxygen concentration caused by the discharge of iron-rich ground water were discussed.

A Study of the Aquatic Habitats of Hyde and Gorley Commons.
As part of a major environmental review of a new nature reserve, we performed a baseline study of the habitat. This revealed the presence of the Fairy shrimp *Chirocephalus diaphanus.* The report detailed a management plan for the aquatic habitats and creative conservation ideas for improving the reserve.

Computer Programs

Species Diversity and Richness II
This is a commercially available windows program that has been developed to simplify the use of diversity indices and richness estimators. It calculates all the commonly used diversity indices and richness estimators. In addition, it also can calculate diversity ordering graphs, which is probably the most powerful methodology available for establishing differences in diversity between samples, fit data models simulate data and perform specialist analysis.

Dynamica II
A program which allows the investigation of community of fish and crustaceans in the Severn Estuary. Program is based on a 19 year time series of 75 species of fish and 8 species of macro crustaceans collected from Hinkley Point Power station.

Community Analysis Package
A program to perform the commonly used community analysis methods. It calculates TWINSAPN, PCA, DECORANA, Cluster analysis, MDS, association analysis and many more. All methods are easy to use and presented in a familiar Window environment.

E3
An Environment Management System designed to help companies achieve BS 7750 and ISO 14000.It performs the Environmental effects evaluation of a company and forms the various environmental registers required by these standards. Published by The Stationary Office

EXTERNAL PUBLICATIONS

Henderson, P A, **Seaby, R**, and Marsh, S J. 1990. The zoogeography of the Common Shrimp *(Crangon crangon)* in British waters. *Journal of Marine Biology* **70**: 89-97.

Seaby, R M H, Spelling, S M and Young J O. 1991. The duck leech *Theromyzon tessulatum* (O F Muller) in Crose Mere, Shropshire. *Naturalist* **116**: 61-64.

Young, J O, Martin, A J, and **Seaby, R M H.** 1993. Competitive interactions between lake-dwelling leeches *Glossiphonia complanata* and *Helobdella stagnalis*: an experimental investigation of the significance of a food refuge. *Oecologia* **93**: 156-161.

Bamber, R. N., **Seaby, R. M. H.**, Fleming, J. M. and Taylor, C. J. L. 1994. The effects of entrainment passage on embryonic development of the Pacific oyster *Crassostrea gigas. Nuclear Energy* **33.** 353-357.

Martin, A J, **Seaby, R M H** and Young, J O. 1994. Food limitation in lake-dwelling leeches: field experiments. *Journal of Animal Ecology* **63**: 93-100.

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Young J.O., **Seaby R.M.H.**.& Martin A.J., 1995. Contrasting mortality in young fresh water leeches and triclads. *Oecologia* **101**:317-323

Seaby R.M.H., Martin A.J.& Young J.O., 1996. Food partitioning by lake-dwelling triclads and glossiphoniid leeches: field and laboratory experiments. *Oecologia* **106**: 544-550

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Henderson, P. A. & **Seaby, R.M H**., 1999. Population stability of the sea snail at the southern edge of its range. **J. Fish Biol**. **54**, 1161-1176.

Non Scientific publications

Bass catches not hit by surveys. Fishing news 26 August 1994.

A SELECTION OF INTERNAL REPORTS

R Seaby & P Henderson, 1994, Fish and crustacean captures at Hinkley Point nuclear power station, April 1993 to March 1994, **Fawley aquatic research laboratories Ltd**, FCR 092/94

R Bamber & **R Seaby**, 1994, The effects of entrainment passage on planktonic larvae of the common shrimp, **Fawley aquatic research laboratories Ltd**, FCR 095/94

R Bamber & **R Seaby**, 1994, The effects of entrainment passage on planktonic stages of sole, Solea solea L., **Fawley aquatic research laboratories Ltd**, FRR 097/94

R Seaby, 1994, Survivorship trial of the Fish-return system at Sizewell 'B' Power Station, **Fawley aquatic research laboratories Ltd**, FCR 102/94

R Bamber & **R Seaby**, 1994, The effects of entrainment passage on the planktonic larvae of the lobster, **Fawley aquatic research laboratories Ltd**, FRR 103/94

J. Fleming, **R Seaby** & A Turnpenny, 1994, A comparison of fish impingement rates at Sizewell 'A' & 'B' Power Stations, **Fawley aquatic research laboratories Ltd**, FRR 104/94

R Bamber & **R Seaby**, 1994, The effects of entrainment passage on the planktonic copepod *Acartia tonsa* Dana, **Fawley aquatic research laboratories Ltd**, FRR 108/94

R M H Seaby & J D Riley, 1994, Weymouth bay: fish and fisheries review, **Fawley aquatic research laboratories Ltd**, FCR 116/94

AWH Turnpenny, **Seaby R**, Nedwell & Needham, 1994, Underwater sound pressures measured during seismic testing at Redhorn Quay, **Fawley aquatic research laboratories Ltd**, FCR 118/94

Nedwell, Needham, Turnpenny & **Seaby R**, 1994, An investigation of underwater sound propagation in shallow coastal waters, **Fawley aquatic research laboratories Ltd**, FCR 119/94

R Seaby & J Riley , 1994, The young fish community of Weymouth Bay, **Fawley aquatic research laboratories Ltd**, FCR 131/94

A Turnpenny, **Seaby R,** Thatcher, Nedwell & Needham, 1995, Measurements of sound pressures from seismic air gun array Poole Harbour, **Fawley aquatic research laboratories Ltd**, FCR 137/95

R Seaby and P.A. Henderson, 1996, Report on Water Quality in the Keyhaven Reserve: with special reference to the impacts of pumped water from gravel works. PISCES Conservation Ltd, PCK/PISCES/6

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R Seaby, P Henderson and R Wood, 1997, A review of the Report; River Discharge Requirements of Migratory Salmon in the Lower River Itchen. PISCES Conservation Ltd, PCL/PISCES/4

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