CLF EXHIBIT 01

P.A. Henderson, Aquatic Ecology Issues Relating to the Merrimack Generating Station National Pollutant Discharge Elimination System Permit Renewal (2012)

Aquatic ecology issues relating to the Merrimack Generating Station National Pollutant Discharge Elimination System permit renewal

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Executive Summary

This report considers the aquatic environmental issues related to the choice of cooling water system for the Merrimack Generating Station in Bow, New Hampshire. At present the plant uses once-through cooling, which requires the continuous extraction of large volumes of water from the Merrimack River and results in the discharge of heated wastewater back into the river. The current operations impact the aquatic life in a number of ways of which the three most important are as follows: (1) The injury or death, during passage through the cooling water circuit, of small organisms and young life stages; usually termed entrainment losses; (2) The capture, injury and death on the cooling water filter screens of larger aquatic life, in particular fish; usually termed impingement losses; (3) The discharge of warmed water that increases the temperature of the river in the vicinity of the discharge, resulting in adverse impacts on aquatic life; usually termed thermal impacts. In issuing Merrimack Station's National Pollutant Discharge Elimination System Draft Permit ("Draft Permit"), EPA concluded that closed-cycle cooling would reduce these adverse effects to negligible levels and produce an appreciable improvement in aquatic life and the local fish population in particular. This report concludes that the ecological gains from changing to closed-cycle cooling, including reduced impingement/entrainment and lower river water temperatures, far outweigh any negligible adverse ecological effects associated with installing that technology. EPA also concluded, based on PSNH's anti-degradation study, that there is assimilative capacity in the Merrimack River to accept a small amount of mercury in the wastewater discharge. This report concludes that the data underlying the anti-degradation study was not representative of the full range of river chemistry and therefore insufficient to reach this conclusion.

1 Introduction

This report considers the ecological effects on the aquatic environment of once-through cooling as presently used at the Merrimack Station, and the advantages of switching to closed-cycle cooling as proposed by the EPA in the Draft Permit.

1.1 The author

My name is Dr. Peter Alan Henderson. My business address is Pisces Conservation Ltd., IRC House, The Square, Pennington, Lymington, Hampshire, England. I am a Director of Pisces Conservation Ltd. where I work as an ecological and fisheries consultant. I specialise in the ecological effects of large industrial plants, and power stations in particular. I am also a Senior Research Associate at the Department of Zoology, University of Oxford, England, where I lecture in population dynamics and marine ecology. My curriculum vitae is attached to this Report as Exhibit 1.

I received a 1st Class Honours Bachelor of Science in Zoology and Applied Entomology at Imperial College, London in 1975 and was awarded the Governors' Prize for Zoology. I received a Ph.D. in Aquatic Ecology in 1978 from Imperial College, University of London as well.

As noted above, I am a Director of Pisces Conservation Ltd. where I work as an ecological and fisheries consultant. Pisces was established in 1995 by environmental science staff from the UK power industry and major universities. The company specialises in the ecological effects of industry and power plants in particular on the aquatic environment. Pisces has extensive international experience including a number of years of work on power plants in the Hudson valley. Pisces also has a specialist ecological software section that develops computer programs for the analysis of ecological data that is used worldwide. My initial training and experience on power plants was gained while working for the UK power industry at the Central Electricity Research Laboratories where I was employed as an ecological modeller on the impacts of cooling water intakes and discharges. I specialise in the ecological effects of large industrial plants, and power stations in particular. I am also a Senior Research Associate at the Department of Zoology, University of Oxford, England, where I lecture in population dynamics and marine ecology and supervise post-graduate students.

I have more than 30 years of experience as an applied ecologist specialising in aquatic ecology. My specific areas of expertise are in cooling water intakes and power plant engineering, including recent experience working on fisheries issues linked to power plant proposals in the Hudson River, the Red Sea and the Bristol Channel. I have more than 30 years of study of British and South American freshwater and estuarine fish and crustacean population dynamics. I also develop ecological software designed to analyse ecological communities and predict the impact of power station intakes, and lecture on numerical methods for ecologists.

I am the author of three standard ecological textbooks entitled '*Practical Methods in Ecology*', '*Ecological Methods*' and '*Marine Ecology: Concepts and Applications*'. I have authored over 100 technical papers concerning aquatic ecology issues.

1.2 The cooling water configuration of the Merrimack Generating Station

The present Merrimack Generating Station has two cooling water intake systems (CWISs) with a total designed intake flow of 287 million gallons per day (MGD) of Merrimack River water. The Merrimack Station discharges approximately 26.3 trillion British thermal units (Btus) of waste heat in the cooling water discharge each year. The thermal effluent passes along an open canal prior to discharge to the river, which allows time for some of the heat to dissipate. To assist heat dissipation the station installed 224 power spray modules (PSMs) in the discharge canal in an effort to provide additional cooling of the thermal discharge by spraying the heated effluent into the air. This cooling method is unusual and offers only limited or no capacity to remove heat from the discharge stream. This is clearly demonstrated by the difference in the average summer river temperatures between station N-10 above the discharge point and station S-0 at the mouth of the discharge canal after heat removal by the PSMs. In September for the years 1984-2004 the difference in the averaged mean daily temperatures between these stations was 16.9 °F (Attachment D p15 Table 3-1). As the EPA noted, PSNH has stated that the maximum temperature differential between stations N-10 and S-4 must be assumed to be at least 19 °F (Attachment D p134). The low amount of heat removed by the PSMs can be appreciated when it is noted that the increase in temperature across the condensers is a maximum of 23 °F, only 4 °F higher.

2 Impingement and entrainment with once-through cooling

Impingement and entrainment are particularly significant issues with once-through cooling systems like the current cooling system at Merrimack Station. Fish, including fish eggs and larvae, and other organisms enter the intake with the flow of cooling water, and become either impinged on the filter screens or, if sufficiently small, pass through the station via the condensers to be discharged back into the river. EPA has correctly concluded that impingement and entrainment caused by Merrimack Station's historical and current operations has resulted in a significant adverse impact to the Balanced Indigenous Population (BIP) in the Hooksett Pool. Installation of closed-cycle cooling at Merrimack Station will significantly reduce the levels of mortality and injury caused by impingement and entrainment, and therefore promote the recovery of the balanced indigenous populations of both resident and anadromous fish species.

2.1 Impingement of fish and other organisms

Aquatic life is poorly adapted to withstand impingement, and contact with the metal screens frequently results in injury or death. The impingement losses observed due to Merrimack's current intake structures are significant and have affected the abundance of the local fish populations, both resident and migratory.

The word impingement is used here to describe the capture of fish and other organisms on the filter screens of the cooling water intake system. These organisms are washed off the screens, and either collected in a trash basket for subsequent disposal, or, under optimal conditions, are sluiced along a channel and returned to the environment. However, Merrimack Station has been operating without a fish return system, which has apparently resulted in 100% mortality of impinged organisms.

Studies were undertaken by Normandeau Associates on the proportion of fish that survived initial impingement on the screens. This is discussed under the title of *Impingement survival.* However, there is in reality no impingement survival. Normandeau described the present situation as follows:

> *"The current fish return for impingement at Units 1 and 2 ends in*
> *a pit located on the Merrimack Station."*
> (p 56, Normandeau Associates, 2007[1]).

This implies all the impinged fish are killed, although this is not explicitly stated to be the case.

Normandeau Associates' October 2007 report gives information on fish impingement at the Merrimack station. The data were collected between June 2005 and June 2007, and are likely sufficiently recent to reflect present and near future impingement rates with once-through cooling. The percentage of the total cooling water flow sampled on studied days was typically around 10%.

Key findings from this study were as follows:

- 21 fish species were recorded impinged;
- Bluegill most abundant impinged species;
- Maximum impingement is in late fall/early winter and spring/early summer; the highest estimated impingement was in June 2006 when an estimated 2,345 fish were observed impinged, which when corrected for collection efficiency equates to 4300 individuals;

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[1] Entrainment and Impingement studies performed at Merrimack Generating Station from June 2005 through June 2007. Normandeau Associates, 2007.

- Unit 1 impinged an estimated 1,603 and 405 per year for the two years of study June 2005-June 2007[2];
- Unit 2 impinged an estimated 6,736 and 1,271 per year for the two years of study June 2005-June 2007;
- Total impingement losses for the two units are therefore about 8000 fish over a two year period.

The losses are primarily borne by resident, local fish and therefore the losses have affected the abundance and health of the local populations. The importance of impingement losses was noted by the EPA:

> *"At Merrimack Station, impingement occurs on a year-round basis, substantial impingement events occur at times, and significant numbers of the fish that are impinged die as a result. Both resident and anadromous fish are impacted by impingement, and rates of impingement might be even higher if fish populations were healthy. Furthermore, the loss of significant numbers of juvenile and adult fish to impingement is likely to combine with other stressors to interfere with the recovery of fish populations."*
> *(EPA Attachment D p. xv)*

An important point to note here is that the EPA also observed that impingement might appreciably increase with the fish populations recovering to healthy levels. If once-through cooling were to continue at Merrimack Station, I agree with the EPA's conclusion. Accordingly, closed-cycle cooling offers the most effective reduction in harm to aquatic organisms due to impingement.

EPA concluded that seasonal use of closed cycle cooling was BTA for reducing impingement. However, this decision did not offer any increased protection to fish and other aquatic life during the periods when once-through cooling would be used. As stated on p 346 of Attachment D "*...EPA recognizes that the permit's thermal discharge conditions are based on closed-cycle cooling on a year-round basis. As a result, closed-cycle cooling would be in place, and providing even greater reductions in impingement mortality that (sic) would be realized with the screening system improvements included in Option 5."* If a once-through cooling capability were to remain in place, I believe it would be most protective of the aquatic environment to equip the intake with modern technology. The set of best technologies for protecting aquatic life would comprise advanced screens with low through-screen water velocities, low-pressure washing systems, continuous operation and an efficient fish return system. This set of technologies was identified by EPA as a Type-2 Fish Return in Table 12-3 (p 333) and applied, for example to Option 1. It should be applied to Option 5 if once through capability is retained.

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[2] From Table 4-5 p 74 Entrainment and Impingement studies performed at Merrimack Generating Station from June 2005 through June 2007. Normandeau Associates, 2007.

In the draft permit the aimed use of fish protection technologies is clearly stated. To reduce impingement:

> *"All live fish and other aquatic organisms collected or trapped on the intake screens shall be returned to the river with minimal stress." (p 27)*

This is to be achieved using low-pressure wash water on the screens and by the installation of a new fish return system. Such protective technologies can be applied to intakes irrespective of the volume of water pumped. However, in the case of the Merrimack Generating Station installation of such technologies is in my opinion only best applied if the plant retains an open-cycle capability. Under continuous closed-cycle operation it would likely be possible to protect the fish from impingement using a small wedgewire screen assemblage. This technology is dismissed as impractical for application with once-through cooling (p271 onwards of the background document), but this does not reject the use of wedgewire screens with the much smaller intake volumes required with cooling towers. Further, if continuous closed-cycle cooling were used consideration should also be given to siting the intake in the best location to reduce entrainment. For example, egg and larval fish densities tend to be greatest in shallow waters near structures and banks.

However, if fine mesh wedge-wire screens were still impractical with the low intake volumes required for closed-cycle cooling, then the identified screening and fish return technologies when used in conjunction with closed cycle cooling would give a good level of protection and likely lead to low levels of impingement mortality.

2.2 Entrainment of fish and other organisms

Entrainment is used here to describe the fate of organisms that are drawn via the cooling water intake structure into the cooling system. The organisms pass through filter screens, travel along the plant's pipe-work, and are discharged back to the environment with the heated effluent water. During passage they may also be subjected to biocides used to control fouling. Of particular concern is the entrainment of fish eggs and larvae, which are killed in large numbers during passage through a power plant's condensers. Recent studies show that mortality rates of entrained organisms can be as high as 97%, depending on the species and life stage entrained. It is often assumed that 100% mortality occurs. The numbers of young fish entrained by the Merrimack Station and discussed below are large. EPA concluded that entrainment at Merrimack Station "*represents a significant adverse environmental impact*." (Attachment D p254). I concur with EPA's conclusion.

The importance of entrainment was noted by the EPA:

> *"A significant portion of the Hooksett Pool's ichthyoplankton may be lost to entrainment by Merrimack Station because the facility tends to withdraw a sizable percentage of the Pool's flow for cooling. Moreover, this percentage grows in the early summer as river levels drop (and larvae are still present). For example, on average, Merrimack Station has withdrawn approximately 19 percent of the available flow in Hooksett Pool during July. It has withdrawn even more during some years and peak day withdrawals as high as 75 percent have been recorded. Even greater percentages of available flow have been withdrawn in August, although larval abundance is typically reduced during that month. A number of species of importance to the Merrimack River that have suffered significant declines (e.g., yellow perch, white sucker, American shad) are particularly vulnerable to entrainment. Moreover, entrainment of icthyoplankton and other zooplankton may represent a significant reduction in available forage for the fish and other aquatic organisms that typically prey on them. All of this is particularly problematic given the poor health of the Hooksett Pool fish community and its apparent inability to recover under current conditions. Reducing entrainment should not only help facilitate the recovery of the resident fish community, but should also benefit efforts to restore anadromous American shad in the Merrimack River watershed. ."*

(EPA Attachment D p. xv)

Normandeau Associates (October 2007[3]) reported on fish entrainment. Key findings from this study were as follows:

- Between 21 May and 16 Sept 2006 about 2.8 million fish were entrained;
- Between 1 April and 30 June 2007 about 2.4 million fish were entrained;
- The main species entrained were white sucker, yellow perch, minnows and carp;

These numbers are large, and typical for a power plant with once-through cooling. The losses represent an adverse effect on the local fish populations; the impact is particularly important in-combination with the thermal stress and impingement losses. While it would be possible to reduce impingement losses with a fish return system, an appreciable reduction in entrainment without switching to closed-cycle cooling would be difficult, and likely technically infeasible.

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[3] Entrainment and Impingement studies performed at Merrimack Generating Station from June 2005 through June 2007. Normandeau Associates, 2007

As an approach to put these huge entrainment numbers into context, the losses are calculated as Adult Equivalent (AE) numbers (Normandeau, 2007). This is an attempt to estimate the number of adult fish that the eggs and larvae lost to entrainment would have produced. For white sucker, the AE loss for 2006 was calculated as 7,337 fish. This is an appreciable loss to the local population, and indicates that entrainment losses are important.

The entrainment survival studies reported in Normandeau (2007[4]) failed to produce useful results; together with my review of the literature I have concluded that there is therefore no evidential basis for assuming that the young stages of fish survive passage through this power plant in significant numbers. Thus, I agree with EPA's decision to assume 100% mortality of entrained organisms.

3 Thermal pollution with once-through cooling

As will be discussed below, on grounds of scale and the maximum temperature generated, the thermal discharge of the Merrimack Station produces a large-scale physical alteration relative to the size of the habitat. This alteration has had a demonstrable adverse impact on the fish community in Hooksett Pool which has lost cold water forms in favour of species more able to withstand thermal enrichment. This clear alteration in the BIP since the late 1960s makes a thermal discharge variance inappropriate.

3.1 Evidence supporting the view that Merrimack Station's thermal discharge appreciably harms the balanced indigenous population of the Hooksett Pool

The relative size of the thermal discharge in comparison with the river flow or pool volume is a key issue when assessing thermal impacts. In part, this is because the larger the size of the receiving water body, the more capacity there is to dilute the warm water effluent. In addition, if the habitat is sufficiently extensive mobile organisms such as fish may avoid the warmest zones where they can be harmed.

In the case of the Merrimack Station, a notably high proportion of the river volume is extracted for cooling, so that the effect of the thermal discharge on river life is a key ecological issue. This has long been recognised. The Merrimack River Thermal Study (1971) by P. H. Wightman[5] noted that:

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[4] Entrainment and Impingement studies performed at Merrimack Generating Station from June 2005 through June 2007. Normandeau Associates, 2007

[5] Wightman, P.H. (1971). Merrimack River Thermal Pollution Study. Division of Inland and Marine Fisheries, New Hampshire Fish and Game Dept.

> *"... a considerable portion of the river during low flows is subjected to use for condenser cooling purposes. There are times when the total flow of the river through regulation by hydro facilities upstream is less than the required intake for full production at the Bow plant."*

In addition to the scale of the discharge the maximum temperature of the discharge is also a key variable determining the level of harm. This is because the maximum temperature defines the upper constraint on the range of temperatures that a species must be able to withstand if it is to persist and flourish in the habitat. Even if the temperature is within the range tolerated almost all of the time, a species will still be lost if conditions move outside this range just once or twice in a generation.

At monitoring station S-0, situated at the end of cooling canal, temperatures regularly break 90°F and can exceed 100°F. Normandeau (2007)[6] in appendix A present data on minimum, mean and maximum temperatures recorded at station S-0 between 1984 through 2004. This shows that for 11 days in July temperatures greater than 100 °F have been recorded. Similarly, during August, 16 days have values greater than 100 °F. It is clear that exceedingly high temperatures frequently occur at station S-0. Further, the water temperature at the end of cooling canal has a recorded summer maximum of nearly 105°F.

The temperature of the water at S-0 is important to river life because planktonic organisms and life forms unable to swim will be exposed to these high temperatures as the discharge mixes with the river water. This entrainment into the warm water discharge can result in death or injury. The consideration of the temperature requirements of yellow perch offer a clear example of the harm this discharge can inflict. Yellow perch larvae are known to be present in the water over May and into early June. Koonce *et al* (1977)[7] report that the upper lethal temperature giving 100% mortality of the larvae is 86°F, while 45% morality occurs at a temperature of 80.6°F. Normandeau (2007) in appendix A show that in May between 1984 through 2004, station S-0 had maximum temperatures in excess of 86°F on 13 days and above 80.6 on 29 days. It is clear that larval yellow perch entrained into the mixing zone of the discharge will be harmed and can be killed. Their fate will depend on both the maximum temperature they are exposed to and the duration of contact.

I conclude that yellow perch larvae in Hooksett Pool have suffered increased mortality because of thermal pollution and this will have contributed to the decline of the species since the 1960s.

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[6] Normandeau (2007) A probabilistic thermal model of the Merrimack River downstream of Merrimack Station.

[7] Koonce, J.F., T.B. Bagenal, R.F. Carline, K.E.F. Hokanson, and M. Nagiec. 1977. Factors influencing year-class strength of percids: A summary and a model of temperature effects. J. Fish. Res. Board Can. 34:1900-1909.

Data from Station S-4 downstream from the discharge point give a measure of surface water temperature in the lower Hooksett Pool, and data from Station A-0 in Hooksett Dam tailwaters a measure of the fully mixed temperature. In the main stem of the Merrimack River, downstream of the discharge canal, maximum temperatures at S-4 in July and August have regularly exceed 90°F, and the maximum recorded between 1984 and 2004 was 97.9°F (August 16th). A temperature of 90 °F is approximately 32°C, which is above the upper avoidance temperature for all the Hooksett Pool BIP fish species listed in Table 1 below. There is therefore evidence that the discharge will harm fish, by excluding them from a large area of available habitat within Hooksett Pool. There is also substantial far-field heating to the river as demonstrated by temperature records for Station A-0, which is known to generate deleterious impacts on river life. Note that the upper growth temperature for the fish listed in Table 1 is 31.6°C (about 89°F) or less. The maximum temperature in the summer months of July and August at monitoring Station A-0 is above 89°F on 20 days. This demonstrates that thermal pollution must be affecting fish growth. Needless to say, all of these temperatures are far above the *optimum* temperatures for fish in the balanced indigenous population of the Hooksett Pool.

Table 1: The water temperature requirements for a selection of fish collected in Hooksett Pool 1967-69 and identified as BIP species by the EPA. Temperatures are given in degrees Celsius with Fahrenheit in parentheses. Optimum: the temperature at which the fish is most effective. Growth: the maximum mean average weekly temperature for growth. Upper avoidance: the temperature at which the fish will avoid (varies with acclimation temperature). UILT: the upper incipient lethal temperature above this temperature the fish cannot survive indefinitely. ***From Yoder & Rankin, 2005 Temperature Criteria Options for the Lower Des Plains River – US EPA region V.***

Species	Optimum	Growth	Upper avoidance	UILT
White sucker	26 (78.5)	27.8 (82)	28.7 (83.7)	31.5 (88.7)
Largemouth bass	29.1 (84.4)	30.9 (87.6)	31.6 (88.9)	34.5 (94.1)
Smallmouth bass	30 (86)	31.6 (88.9)	32 (89.6)	34.7 (94.5)
Pumpkinseed	28.4 (83)	30.5 (86.9)	30.5 (86.9)	34.6 (94.3)
Yellow bullhead	28.3 (82.9)	31 (87.8)	31.3 (88.3)	36.4 (97.5)
Redfin shiner	28.6 (83.5)	30.5 (86.9)	31.9 (89.4)	34.2 (93.6)
Walleye	22.8 (73)	26.2 (79)	30 (86)	32.9 (91.2)
Yellow perch	22.6 (72.7)	26 (78.8)	29.8 (85.6)	32.9 (91.2)

Anadromous and catadromous fish are also adversely affected by thermal pollution, although for these species their exposure time may be limited, and concerns focus more on their ability to pass through the region with elevated temperatures. These issues are discussed further below.

3.1.1 Protective water temperatures to meet New Hampshire’s Water Quality Standards

To ensure that the technology-based thermal discharge limits would also result in compliance with New Hampshire's Water Quality Standards, EPA developed water quality-based thermal discharge limits. The approach taken was to identify the most temperature sensitive resident and diadromous fish and identify for each the upper temperature limits for the different life stages present. It was assumed that these limits would then be protective for other species believed to be more tolerant to elevated water temperatures.

Yellow perch was identified as the most temperature sensitive resident fish. Anadromous fish are generally more sensitive to high water temperatures and various life stages of American shad, Atlantic salmon and Alewife were all included in the analysis. I consider this choice of resident and diadromous species as appropriate for the analysis undertaken.

The identification of the upper temperature limits for different life stages of a number of fish has resulted in a sequence of 13 different maximum protective temperatures over the year (EPA Attachment D p 215, Table 9-3). Further, they are defined at two different localities (Stations S-0 and S-4), at different depths (1 and 3 feet below the surface) and are averaged over different time periods (hourly maximum or weekly average). All of these variations in compliance point, water depth and monitoring schedules are based on sound science relating to the ability of the fish to survive the thermal effluent. However, as I explain below they likely will not have the intended result of maintaining a balanced indigenous community. This is because they focus on the physiological requirements of the single species and do not consider competitive interactions between species.

A key point to note is that for certain periods of the year the maximum mean protective temperatures given in Table 9-3 are higher than the maximum mean temperatures calculated for the present operation. The most extreme example is between October 1st to November 4th, the maximum mean protective temperature is defined using the requirements of yellow perch juveniles as 28.4 °C (83.1 °F) as a weekly mean at Station S-4 compared with the present maximum mean temperature at this station of 18.8 °C (65.8 °F). The value of 28.4 °C is not based on direct experimental or field observation, but on a calculation in which a factor of one third the difference between the physiological optimum temperature and the upper lethal temperature is added to the physiological optimum temperature:

26.4 + 1/3(32.3-26.4) = 28.4 (EPA Attachment D, p 192).

This calculated temperature of 28.4°C (83.1°F) is actually above the upper bound of the possible range of the physiological optimum temperature for yellow perch given by the EPA as 28°C (82.4°F) and well above the average physiological optimum temperature of 26.4°C (79.5°F). In Table 1 above the maximum temperature for growth for yellow perch is 26°C, close to, but, below the average physiological optimum calculated by the EPA. If accepted, this maximum protective temperature would ensure that, for a large area of the lower Hooksett Pool, the surface waters would have a temperature above the physiological optimum for yellow perch juveniles. This is important because a temperature above the optimum may alter the competitive outcomes between coolwater and warm water species, for example yellow perch and blue gill. As will be discussed below it has been clearly shown that since the 1960s the population of blue gill has increased while the yellow perch has declined. There is therefore direct field evidence that the present temperature regime is not protective of yellow perch. I conclude that the EPA's water quality based standards are not sufficiently protective because they are not based on an analysis of the competitive advantage between cool and warmwater species and therefore they are not designed to ensure the maintenance of a healthy balanced indigenous community. The EPA has not demonstrated that their water quality based limits would not favour warmwater species over the coolwater species naturally occurring in this habitat.

3.1.2 Field evidence for thermal impacts on fish

Background information on the response of fish to heated water is given in Appendix 2.

The first systematic biological sampling of Hooksett Pool was undertaken in 1967 prior to the commissioning of Merrimack Station's Unit 2 in 1968. Given the lack of data prior to the commissioning of Unit 1 in 1960, the EPA considered the community in 1967-69 to represent the balanced, indigenous population (BIP) against which the thermal discharge should be assessed. Since it is quite likely that the fish community present in 1967 had already been impacted by thermal pollution and so was different from that present in 1960, the approach taken by the EPA is therefore balanced in favour of the power plant. However, this is the only available starting point for analysis and there are arguments to suggest that the bias in favour of the power plant will not be sufficient to cloak the detection of subsequent thermal impacts. The 1967-69 data are likely to give an indication of the BIP in 1960 for two reasons; (1) Because unit 2 greatly increased the total designed flow discharge from 86.4 to 286.6 MGD; and (2) Communities generally respond slowly to thermal pollution and so by 1967 many features of the populations in 1960 were still likely to be present. I therefore conclude that the fish community recorded in 1967-69 can be used to define the BIP against which the subsequent effect of the thermal discharge can be measured.

It is notable that the analysis presented by the power plant did not consider data from the 1960s. The result was that they did not use an appropriate BIP against which to assess the effects of the thermal discharge.

As presented on Table 5-1 (EPA Attachment D, p32) in 1967-69 the fish community was divided into guilds defined by temperature. Species membership of the temperature guilds were as follows: Coldwater – 1 species: Coolwater – 10 species: Warmwater – 10 species. One species, the brown bullhead, was classified as in both cool and warm water guilds. It is clear that in the late 1960s the Hooksett Pool held a mixed warm and coolwater fish community. Since that time the evidence shows that the community composition has changed greatly in part due to the introduction of warmwater species and also the decline in coolwater forms. The warmwater species could not have out-competed the coolwater forms without a thermal regime which favoured their physiology. This switch to a warmwater dominated community is telling evidence in favour of a change in community driven by increased water temperature. Further, the abundance of fish in Hooksett Pool has declined and this decline is most marked in coolwater forms such as the yellow perch.

The existence of important thermal impacts on aquatic life has been recognised by the EPA:

> *"the evidence as a whole indicates that Merrimack Station's thermal discharge has caused, or contributed to, appreciable harm to Hooksett Pool's BIP. For example:*
>
> - *The Hooksett Pool fish community has shifted from a mix of warm and coolwater species to a community now dominated by thermally-tolerant species;*
> - *The abundance for all species combined that comprised the BIP in the 1960s has declined by 94 percent, and*
> - *The abundance of some thermally-sensitive resident species, such as yellow perch, has significantly declined."*
>
> *(EPA Attachment D p. viii)*

A likely example of a warmwater species out-competing coolwater forms is the appearance and increase in bluegill. Bluegill are known to prefer warmer waters than yellow perch and will enter waters of higher temperature to feed. Further, they will continue to grow at higher temperatures than yellow perch. Bluegill were not present in the 1967-69 sampling data. As water temperatures in Hooksett Pool increased, the environment allowed bluegill to continue to grow and feed at certain times of the year and in parts of the habitat where yellow perch would leave, avoid entering, or become dormant and cease feeding. In addition, as described above yellow perch larvae have been exposed to lethal water temperatures close to the discharge point. I conclude that conditions within Hooksett Pool have given advantage to warm water species and these have gradually become dominant, to the detriment of the indigenous coolwater forms.

3.2 *Thermal impacts on migratory fish species*

In addition to permanently resident fish, the Merrimack River supports migratory species which move along the river between spawning and feeding grounds. Anadromous species spawn in freshwater and catadromous species spawn at sea. Anadromous species found in Hooksett Pool are Atlantic salmon, American shad, and alewife[8]. The only catadromous species is the American eel. The anadromous species are all notably sensitive to artificially elevated water temperatures. For example, there is a considerable literature relating to the effects of thermal discharges on the migration of salmonids (See Appendix 1 below).

At present, the upstream movement of migratory fish such as alewife is restricted by Hooksett dam, but it is known that adults and juveniles migrate downstream via Hooksett Pool after they are stocked upstream. Alewife are known to avoid temperatures greater than 77°F (25 °C) (EPA Attachment D at 89). It is therefore clear that the present temperature regime within Hooksett Pool between June and mid-September is frequently unsuitable for this species. Much the same arguments could be made for American Shad and the Atlantic salmon, if restoration efforts remove restrictions to movement the present thermal regime in Hooksett Pool will likely become an important habitat constraint.

3.2.1 Thermal pollution and salmon movement

There are moves to re-establish Atlantic salmon and American shad, which are cold water migratory fish, to the Merrimack River. Because of concerns that the thermal effluent would inhibit migration, Normandeau Associates in a 2006 report presented results of a salmon tagging study[9]. The basic concept was to radio-tag then release salmon smolts above the Merrimack Station, and follow their movement past the station. This study certainly showed that the salmon passed by the thermal discharge. However, the report does not present convincing evidence that the discharge would not interfere with normal behaviour. The observed salmon were collected from a hatchery, anesthetized, had a tag inserted into their stomachs, and were then released. Following such treatment it is unlikely that their behaviour was normal, and their passage downstream and past the thermal discharge could have simply been the response of a disorientated and scared fish.

Over the years, many studies have been performed involving the tagging and release of salmon, so the effects of tagging are very well documented. Trefethen and Sutherland (1968)[10] reported: *"Fish released during periods of*

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[8] The EPA noted that blueback herring and sea lamprey may be occasionally present, but are not considered further here.

[9] Normandeau (Normandeau Associates, Inc.). 2006b. Draft Report, Merrimack Station Thermal Discharge Effects on Downstream Salmon Smolt Migration. 38 pp. plus appendix.

[10] Trefethen, Parker S., and Sutherland, Doyle F. (1968). PASSAGE OF ADULT CHINOOK SALMON THROUGH BROWNLEE RESERVOIR, 1960-62. Bureau of Commercial Fisheries Biological Laboratory, Seattle, Washington 98102. Fishery Bulletin: Vol. 67, No. 1

constantly high water temperature in 1961-62 suffered losses, which may have been caused by stress during tagging. Some salmon with sonic tags were initially disoriented when released into the reservoir; …". Further, Giorgi *et al.*[11] note: "*Handling effects may persist from one to several reaches downstream of the initial release location; furthermore, the more intrusive the tagging procedure, the greater the probability for such an effect to occur.* "

I conclude that this study is an unsuitable basis on which to support a claim that the thermal discharge will not interfere with salmon smolt migrations in the downstream direction.

The upstream movement of returning adult salmon has not been analysed because of lack of access. As with other migratory fish, should restrictions to migration be removed or bypassed, the thermal regime in Hooksett Pool will come into focus and will become a key habitat constraint for the re-establishment of the population.

3.3 Thermal impacts on other aquatic organisms

The EPA focuses on the effects of thermal pollution on fish which are the largest and dominant higher organisms in the habitat and potentially of recreational and economic value to man. However, they are only one component in a BIP and it is important to recognise that the entire aquatic system needs to be healthy if the fish community is to be supported.

Almost all aquatic life is affected by thermal discharges. While the term entrainment is commonly used to describe the process in which planktonic animals are drawn into and pass through the condenser circuits of power plants, the term can also be used to describe the capture of organisms in an effluent discharge. When warm water is discharged to a river it mixes with the receiving waters. Any small organisms in the receiving water with which it mixes will be subjected to sudden changes in temperature that are potentially harmful. The importance of these impacts will be in part determined by both the temperature and volume of the discharge. Other factors that may be important are the duration of the exposure, and the presence of biocides such as low levels of chlorine or copper used to control fouling.

Several studies have shown that species diversity of phytoplankton decreases in areas consistently heated to over 30°C (mid-80s °F). The available data would suggest that phytoplankton productivity as measured by carbon assimilation rates declines with increasing temperatures above about 20°C (68 F). When water temperatures reach 35 – 38°C (95-100°F) zooplankton abundance declines and mortalities occur. Water temperatures above 95°F do

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[11] Albert Giorgi, John Skalski, Chuck Peven, Mike Langeslay, Steve Smith, Tim Counihan, Russell Perry, Shane Bickford. PNAMP Special Publication: Tagging, Telemetry, and Marking Measures for Monitoring Fish Populations, Chapter 3.—Guidelines for Conducting Smolt Survival Studies in the Columbia River. Published by Pacific Northwest Aquatic Monitoring Partnership; www.pnamp.org.

occur as a result of Merrimack Station's current thermal discharge, so harm to zooplankton is inevitable.

Thermal impacts on plankton have been previously noted. The Merrimack River Thermal Pollution Study (1971)[12] abstract observed: "... *as well as an indication the planktonic population is affected to some degree by the heated effluent*."

Benthic invertebrates comprise the worms, insects and other generally small organisms that live on or in the bed of the river. They are an important component in the food web of all shallow aquatic ecosystems. As noted by the EPA: "*The number and distribution of bottom organisms decrease as temperature increase. The upper limit for a balanced benthic population structure is approximately 32°C* (90°F) (USEPA, 1986)." This indicates that the benthic invertebrates in Hooksett Pool are likely to be adversely affected by the present thermal discharge. It is frequently argued that because heated water floats the benthos will not be impacted. However, it should be remembered that an important component of the benthic community lives in shallow water along the banks of rivers. These sheltered habitats are particularly important feeding grounds for juvenile fish. It is known that the thermal plume from the Merrimack discharge impacts the banks of the river and therefore will degrade this important part of the ecosystem.

Further, data from Station A-0 show that when the discharge and river water are well mixed, and therefore impacting the river bed, maximum temperatures in August and July do, on occasion, exceed 90°F. I conclude that the benthos in Hooksett Pool will be adversely affected by thermal pollution from the Merrimack Station.

The degradation of plankton, invertebrate and fish populations will inevitably have an adverse impact on the food available to non-aquatic top predators, which in this system would be piscivorous and invertebrate-feeding fish.

3.4 Evaluation of the variance request

Under 316(a) of the Clean Water Act, a variance in thermal discharge permit limits is allowed if the permitee can demonstrate that the technology-based permit limits "*will require effluent limitations more stringent than necessary to assure the pro[t]ection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water into which the discharge is to be made ...*"

The key scientific issue is the protection and health within the water body of a balanced, indigenous population (BIP) of shellfish, fish and wildlife. The Merrimack

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[12] Wightman, P.H. (1971). Merrimack River Thermal Pollution Study. Division of Inland and Marine Fisheries, New Hampshire Fish and Game Dept.

Station has argued for a variance based on the Fisheries Analysis Report which claims that over the years of operation the plant has not caused appreciable harm to the BIP in Hooksett Pool.

To the contrary, as EPA concluded, there is clear evidence that thermal pollution has caused appreciable harm to the BIP of Hooksett Pool; therefore I conclude that the EPA was correct to reject the 316(a) variance request. I discuss below several of the reasons that Merrimack Station's Fisheries Analysis Report is scientifically flawed.

A key aspect of the trends analysis in the Fisheries Analysis Report was the analysis of population trends for selected fish species in sections of the habitat upstream and downstream of the cooling water discharge point. The area upstream has an ambient water temperature without the influence of the power station. It was therefore argued that if both downstream and upstream areas showed the same population trend, it could not be caused by the thermal discharge. Using statistical terms, the upstream site is defined as a control against which the thermal discharge impact can be measured. However, because fish are mobile, there is no reason why the upstream and downstream areas do not hold parts of the same population, the population which is impacted by the thermal discharge. It is therefore inappropriate to use the upstream area as a control. This was also the view expressed by the EPA (EPA Attachment D, p 42), with which I fully agree.

When examining for trends, it is always important to extend the time series for as long as possible and to take the time series back to close to the time when the thermal pollution first commenced. This is important because otherwise major changes may be missed and the natural variability may make the level of subsequent change difficult to detect. It is therefore essential to use the 1960s data in a retrospective analysis because this is around the time when unit 2 was commissioned. These data were not used in the Fisheries Analysis Report, an omission which leads me to reject the claim that there is evidence for *no* prior appreciable harm.

When considering the impacts on coolwater fish such as the yellow perch it is important to consider if the observed declines could be linked to large scale climatic change rather than local conditions. The EPA (EPA Attachment D, p 110) correctly considered this possibility. They noted that there are "thriving" yellow perch populations in the Connecticut River and in the Merrimack River above the point of discharge of the Merrimack cooling water. This in my opinion is powerful evidence that the observed decline in yellow perch is not caused by large-scale factors, but is linked to local factors and the cooling water discharge in Hooksett Pool.

4 Cumulative effects

To understand the total aquatic impact of the Merrimack Station it is essential to analyse the cumulative effects of all the environmental stressors acting upon the organisms living in the river. The EPA gave limited consideration to cumulative effects, noting, for example, that yellow perch were adversely affected by thermal pollution, impingement and entrainment. (EPA Attachment D, p110). Similarly, it was noted that white sucker are vulnerable to both the thermal discharge and also entrainment of early stages.

Cumulative impacts within the Hooksett Pool include a number of wider issues that combine with those caused by the power plant to produce a degraded environment. The canalisation and damming of the river has reduced fish migration and movement between feeding and breeding grounds. Further, aquatic pollution from many sources acts to reduce water quality parameters such as oxygen concentration, which is also reduced by thermal pollution. Finally, there is a long-term gradual trend of increasing global temperature which will have the effect of adding to the impact caused by the local thermal discharge. All of these create additional environmental stress for the balanced indigenous population in the Hooksett Pool. The EPA likely concluded that the Merrimack Station's thermal discharge was in and of itself enough appreciable harm to justify denial of the 316(a) thermal variance and requirement of closed-cycle cooling. I agree with that conclusion. The cumulative effects analysis only serves to strengthen the support for the EPA's conclusions in this regard.

5 Closed-cycle cooling requirement

The EPA concluded that closed-cycle cooling is the Best Available Technology that is economically achievable for Merrimack Station. I agree with this conclusion. The EPA could have required a more environmentally stringent technology - dry cooling - which would have effectively eliminated aquatic habitat impacts. Presumably, this decision was a balance between cost and environmental protection. From the aquatic viewpoint taken here closed-cycle cooling is appropriate because it can meet the need for restoring and protecting balanced indigenous aquatic flora and fauna.

5.1 A summary of closed-cycle cooling systems

In closed-cycle cooling systems, heated water that is led through the heat exchanger system is cooled down in a cooling tower, where the majority of the heat is discharged to the environment. In the cooling tower the heated water is distributed over the cooling tower fill, and is cooled by contact with air and collected in a reservoir, after which it is pumped back to the reservoir to be reused as a coolant. The air movement is created naturally or by means of fans that push or pull the air through the tower. Cooling of the water is a result of evaporation of a small part of the cooling water and of sensible heat loss by the direct cooling of water by air, also called convection. The main causes of water loss are evaporation, blowdown, windage, drift, purge (intentional blowdown) and leaks. Intentional blowdown is the draining of water from the circuit necessary to avoid concentration of dissolved solids. To compensate for the blowdown and evaporation, make-up water is added. Generally, the make-up water flow used by an open recirculating system is about 1-10% of the flow of a once-through system with the same cooling capacity. Blowdown generally ranges from 0.15-0.80 m^3/s per 1000 MWth cooled.

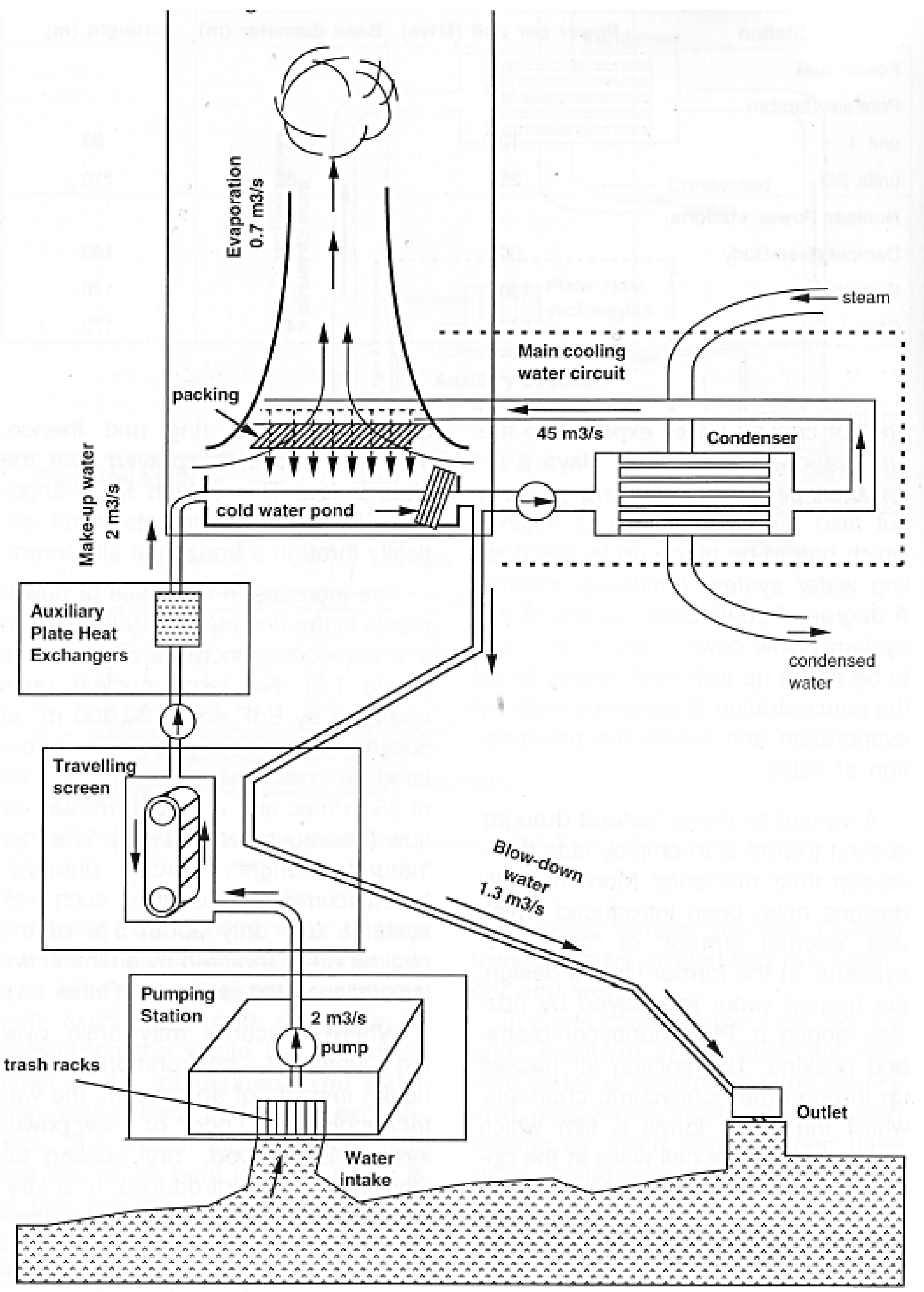

Figure 1: Schematic representation of an open recirculating system. (Jenner *et al* 1998)[13]

6 Water quality issues relating to the use of closed cycle cooling and other technologies

It can be anticipated that objections may be raised concerning the environmental impacts of closed cycle cooling. These and allied issues relating to water quality are considered in this section. Air quality and terrestrial impacts are not addressed.

Re-circulating cooling water system impacts depend on the type of cooling tower and the way it is operated. Impingement and entrainment deaths are reduced to only about 20%, or frequently less than 10% of that caused by a once-through system. The main aquatic impacts are:

- Cooling water additives and their emission through the blowdown to surface water.
- Effects related to the extraction of water, including impingement and entrainment.
- Possibly the loss of surface water to evaporation.

6.1 Water loss from the river associated with closed cycle and once-through cooling

It may be argued that a closed-cycle cooling system results in substantial evaporative water loss to the river, possibly more than currently is occurring. However, a once-through system does generate considerable evaporative losses, and any additional evaporative loss due to closed-cycle cooling is negligible and more than outweighed by other environmental benefits already discussed.

The evaporation of water from a water surface depends upon (1) the water temperature, (2) the air temperature, (3) the humidity of the air and (4) the velocity of the air above the surface. There are other factors that may also come into play such as surface disturbance, but these should not greatly alter the calculations. The above list makes it clear that the water loss from evaporation will vary through time.

The general approach used by engineers is to use an empirical equation. The amount of evaporated water can be estimated using the empirical equation:

$g = \Theta A (x_s - x)$,

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[13] Jenner et al (1998) Cooling water management in European power stations Biology and control of fouling. Hydroecologie Appliquee, 10, volume 1-2 225pp

where
g = amount of evaporated water (kg/h)
Θ = evaporation coefficient (kg/m^2h) = 25 + 19v (v =wind velocity)
v = velocity of air above the water surface (m/s)
A = water surface area (m^2)
x_s = humidity ratio in saturated air at the same temperature as the water surface (kg/kg) (kg H_2O in kg Dry Air)
x = humidity ratio in the air (kg/kg) (kg H_2O in kg Dry Air)

Most of the heat required for the evaporation is taken from the water itself. To maintain the water temperature heat must be supplied, in our case this is continually supplied by the power station discharge.

To show the calculation I give an example for a typical summer day. The calculation is undertaken for the discharge canal only because this will be at a relatively constant temperature moving down the canal. In the river mixing will produce a plume that varies in temperature with distance from the end of the canal, and the calculations would need to be more complex. However, the calculations presented give an idea of the scale of evaporative water losses experienced with once-through cooling. The following section gives an estimate of the total evaporative loss using generally estimated loss rates.

6.1.1 Example calculation – evaporative water loss in summer from the cooling water canal

First I assemble some typical parameter values.

1. **Water temperature**

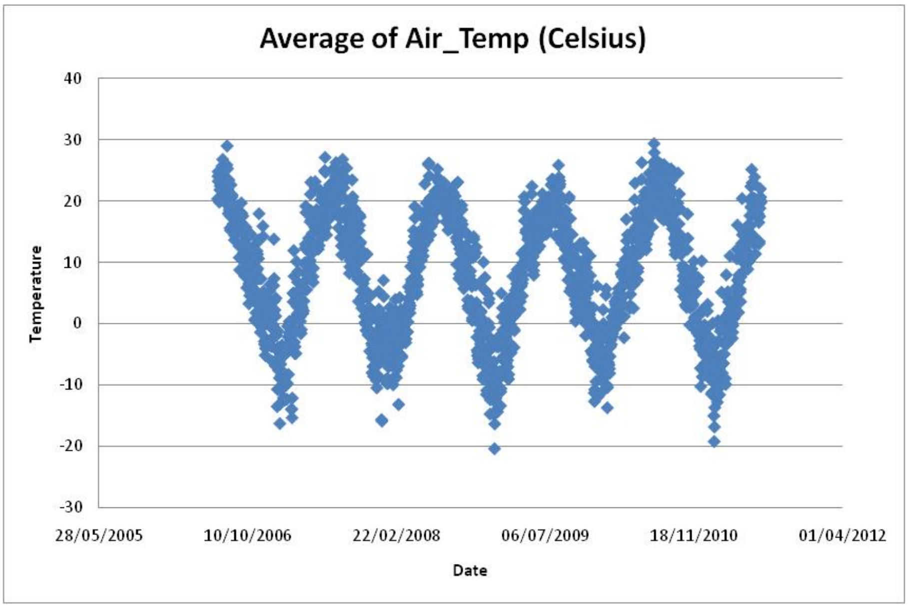
   The water temperature at the end of cooling canal has a recorded summer maximum of about 105°F. At monitoring station S-0, situated at the end of cooling canal, temperatures regularly break 90°F and can exceed 100°F. A temperature of 100°F is approximately 37.78°C. I will therefore use a temperature of 38 °C which is close to, but below, the summer maximum. This will not produce an unusually high estimate of water loss provided we assume similarly high summer values for humidity and air temperature and low summer value for wind speed.

2. **Saturation humidity ratio**

   For a water temperature of 38°C, the saturation humidity ratio is around 0.03 kg/kg.

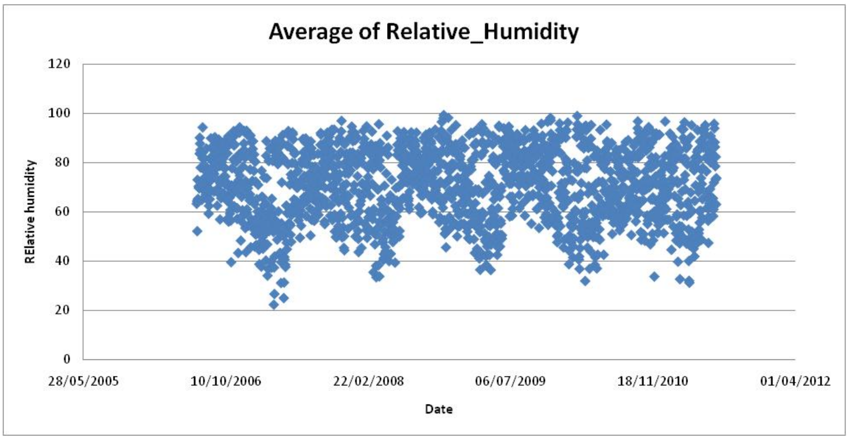
3. **Air temperature**

   The following graph shows the air temperature over the last few years. I will use a summer temperature of 25°C. This is below the maximum observed.



4. Humidity ratio in air

With an air temperature 25°C and 80% relative humidity the humidity ratio in air is about 0.016 kg/kg. The graph below shows the relative humidity for the region indicating that 80% is in the summer range.

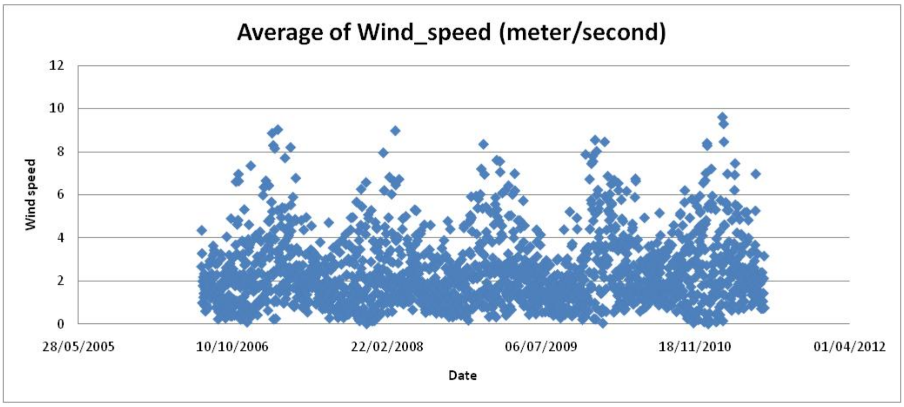


5. The area of water surface over which evaporation occurs

This is difficult to measure and a full model would require consideration of the changing nature of the plume as it disperses in the river. However as a starting point we can estimate the surface area of the discharge canal as about 12,000 m^2.

6. Wind speed

This obviously varies through time. From the graph below a speed of about 2 m/s would seem reasonable.



Now we can make a calculation:

For an area of 12,000 m^2 and 2 m/s velocity of air above the surface, the evaporation can be calculated as:
g = (25 + 19 (2 m/s)) (12,000) ((0.03 kg/kg) - (0.016kg/kg))
= 63 x 12000 x 0.014 = 10,584 kg/h
= 2.94 kg/s.

So over a typical summer day the total weight of water evaporated **from the cooling canal alone** is 10,584 x 24 = 254,016 kg of water.

As 1 litre of water weighs 1 kg this is simply approximately 254,000 litres or 67099.701 US gallons.

The above calculation makes it clear that large volumes of water are evaporated from the discharge canal alone. There will also be considerable evaporation from the river. To make fully accurate calculations would be quite time-consuming; I would need to generate a full thermal discharge model to calculate the surface water temperature at each point in the river, and then use a full seasonal temperature, wind and humidity data set to calculate evaporative loss on each day. However, using the calculations above, I can make calculations for typical days for the discharge canal.

Fortunately, there has been a general analysis of typical water losses undertaken by EPRI and this is presented below.

6.1.2 Estimated total evaporative loss using typical loss rates from a range of power plants

Another approach to assessing relative water loss with once-through cooling and closed-cycle cooling is to examine data calculated over a range of power plants. Such an analysis was undertaken by EPRI *Water and sustainability (Volume 3): U.S. Water Consumption for Power Production – The Next Half Century (2002).* The results table from this study is reproduced below.

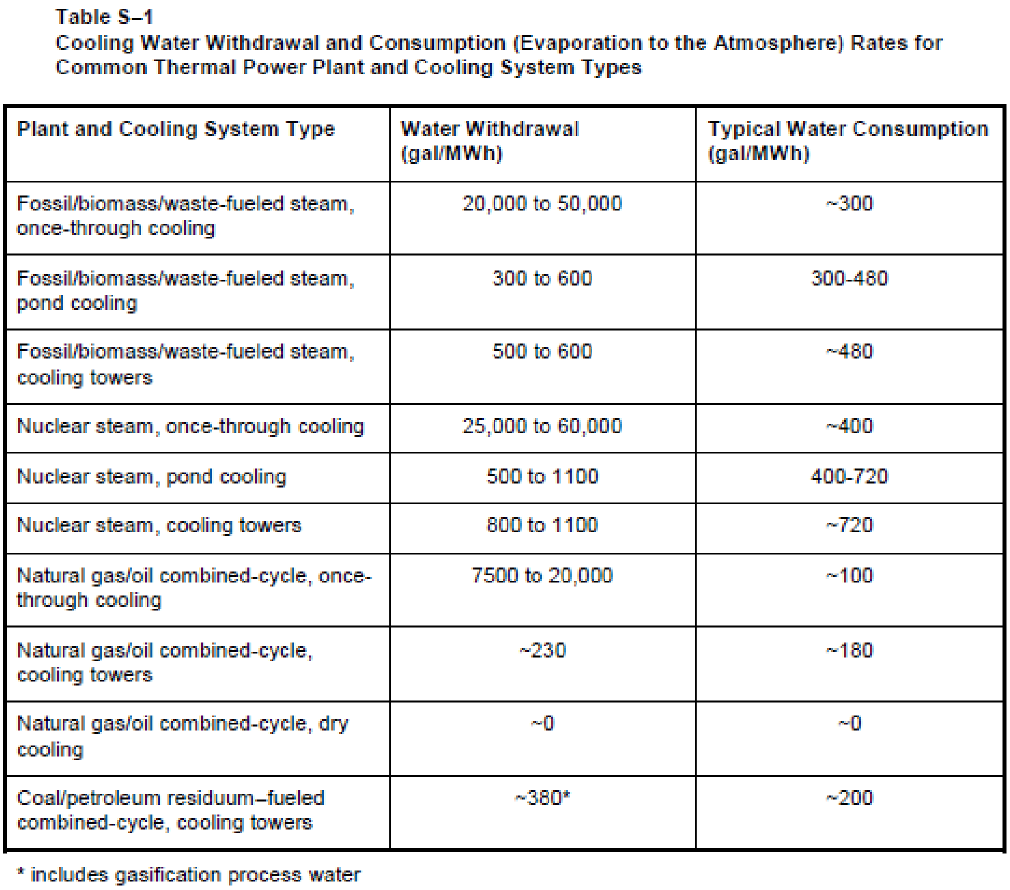


Table S–1
Cooling Water Withdrawal and Consumption (Evaporation to the Atmosphere) Rates for Common Thermal Power Plant and Cooling System Types

Plant and Cooling System Type	Water Withdrawal (gal/MWh)	Typical Water Consumption (gal/MWh)
Fossil/biomass/waste-fueled steam, once-through cooling	20,000 to 50,000	~300
Fossil/biomass/waste-fueled steam, pond cooling	300 to 600	300-480
Fossil/biomass/waste-fueled steam, cooling towers	500 to 600	~480
Nuclear steam, once-through cooling	25,000 to 60,000	~400
Nuclear steam, pond cooling	500 to 1100	400-720
Nuclear steam, cooling towers	800 to 1100	~720
Natural gas/oil combined-cycle, once-through cooling	7500 to 20,000	~100
Natural gas/oil combined-cycle, cooling towers	~230	~180
Natural gas/oil combined-cycle, dry cooling	~0	~0
Coal/petroleum residuum–fueled combined-cycle, cooling towers	~380*	~200

* includes gasification process water

It was concluded that water loss from evaporation for a coal once-through plant is 300 gal/MWh. Using cooling towers, the loss is estimated as 480 gal/MWh. The difference is therefore about 180 gal/ MWh.

The important point to note is that once-through cooling does consume considerable quantities of water. Note that using the EPRI estimate above, the total water evaporative loss when the Merrimack Station is operating at full capacity is 300 x 350 x 24 gallons per day. This is about 2.5 million gallons, which is about 1% of the total volume of water used. To summarise, approximately 1% of the total volume of once-through water used by the power plant will be lost to evaporation. Note that this evaporation is essential as it is the primary path by which the river dissipates the heat injected into it by the power plant.

6.1.3 Current evaporative loss and the impact on river volume

At full capacity (350 MW) the evaporative loss using once-through cooling is estimated as 2,500,000 gallons per day. Now 1 gal (US) = 0.13368 ft^3. This is therefore equal to

$2.5 \times 10^6 \times 0.13368 / 24 \times 60 \times 60 = 3.87 \ ft^3/s$

The flow of the Merrimack River varies greatly through time. During low flow periods it is less than 1000 ft^3/s while at high flow it exceeds 4000 ft^3/s. We will take a worst case low flow situation of 1000 ft^3/s.

The current evaporative loss of river water caused by once-through cooling is therefore 3.87/1000 x 100% of the low flow = 0.387%. This is a low proportion of the total.

In the EPA's Attachment D (p 163), they quote a water loss of 1.3% of the flow, considerably higher than the estimate given above. There are a number of reasons for these differences. First PSNH estimate the water loss for a hybrid cooling tower as 4.79 MGD compared with the EPRI-derived value of about 4 MGD that I used. Much more importantly the EPA compared this water usage to the 7Q10 flow. This is the lowest stream flow for seven consecutive days that would be expected to occur once in ten years. The 10-year flow level gives a value of 587.75 ft^3/s. I chose to use a more typical value of 1000 ft^3/s for my calculation. If I had used the much more extreme 7Q10 value it would be (6.19/587.75) x100 = 1.05%

6.1.4 Evaporative loss caused by closed-cycle cooling and the impact on river volume

At full capacity (350 MW) the evaporative loss using closed-cycle cooling is estimated as a maximum of 480 x 350 x 24 gallons per day = about 4,000,000 gallons per day. This is therefore equal to

$4 \times 10^6 \times 0.13368 / 24 \times 60 \times 60 = 6.19$ ft^3/s

So at low flow conditions of 1000 ft^3/s closed-cycle cooling would consume 6.19/1000 x 100% of the flow = 0.619% of the flow. As is the case with once-through cooling above, this is a small proportion of the total flow**.**

6.2 Conclusions on the balance of harm between once-through and closed-cycle cooling

The benefits of closed-cycle cooling are set forth below:

1. Much reduced water consumption would allow almost complete elimination of fish impingement losses.
2. Entrainment loss of aquatic life would be reduced by approximately 95%, and with a fine screen over the intake would be reduced even further.
3. The thermal plume would be greatly reduced and thermal pollution of the river caused by the plant reduced to negligible levels.

I conclude that the net gains from evaporative cooling on aquatic life in the river greatly exceed any potential costs associated with water loss, and the discharge of cooling tower blowdown water holding increased solutes. This blowdown water is not toxic and the increased solute concentration can be rapidly dissipated using a diffuser on the discharge pipe.

7 Comments on Merrimack Station's Anti-degradation Study

Merrimack Station's new FGD system essentially transfers chemicals, including mercury, previously released to the atmosphere to solid and aqueous waste streams. I consider here inputs to the river primarily via the aqueous waste stream. The Draft Permit requires scrubber blowdown to be treated in a physical-chemical wastewater treatment system (WWTS) with additional biological treatment and a polishing step, with the effluent then discharged to the river. To allow this discharge, an anti-degradation study is required. While the NHDES and the USEPA directed that a range of chemical species be investigated, mercury is a focus of concern because of the potential toxicity and the fact that surface waters in New Hampshire are known to have elevated mercury levels.

Mercury is a toxic, persistent, and bio-accumulative pollutant, which is listed by the EPA as a hazardous air pollutant under the federal *Clean Air Act*. Because of the way it concentrates towards the top of the food chain and attaches to sediment, limiting mercury discharges is critical to the health of the ecosystem.

Since industrialisation began, there has been a gradual build-up of mercury contamination. This has resulted in an increase in mercury levels in fish flesh and the issuing of advisories to limit fish consumption in many water bodies. For instance, all New Hampshire surface waters are listed as impaired for mercury because of fish tissue mercury concentrations, which has led to a state-wide fish consumption advisory.

When dealing with chemical releases, both the concentration of the chemical, and the total amount released, are potentially of significance. The total quantity of mercury released must be considered because it is a bio-accumulator which is retained by the ecosystem and therefore can gradually increase in concentration in the sediments and organisms of Hooksett Pool.

Hookset Pool is defined as impaired for mercury and therefore does not have assimilative capacity for additional mercury inputs. There must therefore be a demonstration that the discharge will produce no net mass increase. Although the Hooksett Pool is impaired for mercury, Merrimack Station's anti-degradation study concluded that there was still assimilative capacity in the river for mercury. As discussed below, I conclude that the data relied on in the anti-degradation study was insufficient to reach such a conclusion.

7.1 *Calculation of the required discharge concentration for no net mass increase*

This calculation for confirming no net mass increase in mercury from the proposed discharge is derived from an examination of the concentrations and flows in the various streams of water.

The maximum allowable WWTS effluent level is defined by the following mass balance inequality:

$(K_{max\text{-}WWTS} \times Q_{WWTS}) + (K_{max\text{-}TP} \times (Q_{TP(F)} - Q_{FGD})) < (K_{max\text{-}TP} \times Q_{TP(P)})$

In words, the concentration of mercury multiplied by the total water flow (the mercury mass) after the installation of the FGD plant must be less than the mercury mass observed before FGD operation.

These calculations are dependent on accurate and representative data for the present concentration of mercury in the river and the treatment pond. The need for representative data is apparent when it is considered that the total mass depends on multiplying a very low concentration value by a very large flow volume. Small sampling errors in the concentration of mercury, which are inevitable when small numbers of samples are taken, become greatly magnified by the volume. It is notable the generation of statistical uncertainty as to the possible range of a value caused by small sample sizes have been noted previously in Hooksett Pool studies. In the Hooksett Pool Waste Water Treatment Facility Antidegradation Water Quality Study (AR-515) it is noted that only 4 samples were available. This resulted in *“ a high coefficient of variation (CV), which in turn, yields a high multiplying factor. The factor is multiplied to the maximum value in the dataset, so the resulting number is elevated.”*

As will be discussed below, this is a key issue that needs to be addressed, as it generates uncertainty in the anti-degradation analysis which has not been adequately considered.

7.1.1 The sufficiency of present water quality data

To date the water sampling data used for the anti-degradation calculations were collected over a limited time period. The river sampling was undertaken between June 2009 and September 2009. Measurements in the treatment pond were for the period June 2009 to January 2010 (URS Executive Summary of Anti-degradation Study p 2).

It is well known that water quality and the concentrations of contaminants vary through time. There are many reasons for this temporal variation. For example, mercury bioaccumulates in living organisms and in organic rich sediments. The natural seasonal cycles in the growth and death of organisms can cause mercury to be assimilated and released at different rates over the seasons. Bacterial activity in the sediments can also change the release and capture rates of mercury. The concentration of mercury may also vary with the other chemical species in the river water. For example, after snow melt, acidity may be increased, and this can mobilise heavy metals. Finally, periods of drought and low flow may increase concentrations. The recent study by Lombard et al (2011)[14] on mercury deposition in New Hamspire illustrates typical patterns of temporal variability. They concluded that "*Total aqueous mercury exhibited seasonal patterns in Hg wet deposition at TF. The lowest Hg wet deposition was measured in the winter with an average total seasonal deposition of 1.56 µgm*$^{-2}$ *compared to the summer average of 4.71 µgm*$^{-2}$*. Inter-annual differences in total wet deposition are generally linked with precipitation volume, with the greatest deposition occurring in the wettest year.* " This study illustrates both seasonal and between year variability in mercury fluxes.

To produce reliable calculations it is necessary to have representative mercury concentration data over at least two full years and if the between-year variation is high, for possibly a further two. Such a data set would both adequately reflect the seasonal cycle and also allow for between-year variation.

I therefore conclude that the mercury concentration data available to the anti-degradation study is presently inadequate to say with reasonable scientific certainty that the Hooksett Pool is not impaired for mercury. I would recommend that at least two years worth of sampling data be collected from both locations to provide a truly representative picture of the mercury impairment of the Hooksett Pool.

The Anti-Degradation Study Executive Summary (p 11) states that additional treatment of the effluent to achieve a value of 0.13 µg/l is required to meet the no net mass increase criteria. This calculation is dependent on the concentration of mercury measured in the water and given the limited sampling must be subject to appreciable uncertainty. As this calculation is subject to statistical uncertainty then there must be uncertainty as to whether this is the appropriate concentration to ensure no net mass increase. Under such circumstances a prudent course would be to ensure no mercury was discharged to the river from the FGD plant.

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[14] Lombard et al (2011) Mercury deposition in Southern New Hampshire, 2006-2009. Atmospheric Chemistry and Physics, 11, 7657-7668.

Appendix 1 Thermal pollution and salmon

7.1.2 North American studies on the temperature sensitivity of salmonids

Because of their general sensitivity to temperature, and their economic importance, salmonids are one of the fish groups about which we have good information on their response to temperature.

Altmann & Dittmer (1966)[15] list, from their review, upper temperature tolerances for salmonids of 28°C (*S. salar* and *S. trutta* prolarvae & postlarvae) and 26°C for *S. trutta* alevins (acclimatized at 20°C); upper temperature tolerances for *Oncorhynchus* species were 24-25°C for both juveniles and adults (acclimatized at 20°C). Generally, their data indicate that North American salmonid adults tolerate slightly higher temperatures than do their juveniles (contrary to the findings of Alabaster (1963[16]; 1964[17]) and Alabaster & Downing (1966)[18] who found young stages could "*withstand somewhat higher temperatures than adults*"). The maximum temperature at which *S. salar* eggs will hatch (in experimental conditions) is 10°C.

Brett *et al.* (1958)[19] showed that sustained swimming speed of the sockeye salmon (*Oncorhynchus nerka*) was optimum at 15°C, decreased past 20°C, and rapidly approached the lethal limit at 25°C. Spaas (1960)[20] found the temperature levels "*ultimately lethal*" to salmonids were close to 30°C.

Bouck (1977)[21] stated "*Perhaps no other single parameter has such a determining effect on a fishery as does its water temperature*". Anadromous salmonids feed very little during their spawning run, so increased temperature leading to increased metabolic rate results in increased weight loss during migration - once fat reserves are used up, muscle is converted for energy. Bouck *et al.* (1976)[22] kept adult sockeye salmon (*Oncorhynchus nerka*) at 10°C and 16.5°C. "*Over the test period*" (unspecified) the former lost an average of

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[15] Altmann P.L. & Dittmer D.S. (Eds),1966. Environmental Biology. Fed. Amer. Soc. Exper. Biol., Bethesda, Maryland, USA.

[16] Alabaster J.S., 1963. The effects of heated effluents on fish. Int. J. Air Wat. Pollut., 7; 541 563.

[17] Alabaster J.S., 1964. The effects of heated effluents on fish. Adv. Wat. Pollut. Res., 1; 261 292.

[18] Alabaster J.S. & Downing A.L., 1966. A field and laboratory investigation of the effect of heated effluents on fish. MAFF Fishery Investigations, Series 1, VI(4); H.M.S.O. 42pp.

[19] Brett J.R., Hollands M. & Alderdice D.F., 1958. The effects of temperature on the cruising speed of young sockeye and coho salmon. J. Fish. Res. Bd Can., 15; 587-605.

[20] Spaas J.T., 1960. Contribution to the comparative physiology and genetics of the European salmonidae. III. Temperature resistance at different ages. Hydrobiologia, 15; 78 88.

[21] Bouck G.R., 1977. The importance of water quality to Columbia River salmon and steelhead. Amer. Fish. Soc. Special Publications No.10; 149-154.

[22] Bouck G.R., Chapman P.W., Schneider P.W. Jr & Stevens D., 1976. Effects of holding temperatures on reproductive development in adult sockeye salmon (Oncorhynchus nerka). 26th Annual Northwest Fish Culture Conference Proceedings, Otter Rock, Oregon; 24-40.

7.5% of body weight and still had some fat reserves left; the fish at the higher temperature lost 12% of body weight, with "*visible fat reserves essentially depleted*". The testes were more than 25% smaller at 16.5° than at 10°, and eggs were smaller and lighter, showing a correlation with body weight.

Zaugg *et al.* (1972)[23] found that at temperatures ≥13°C juvenile salmon and steelhead "*have difficulty making the parr-smolt transformation*". Wedermeyer *et al.* (1980)[24] conclude that temperatures ≥13°C inhibit smoltification in both *O. mykiss* and *S. salar*: *S. salar* show greatest downstream migration runs as the temperature rises to 10°C, and smolt runs are over before the water warms to 15°C or more. Further, at elevated temperatures (as may be experienced, for example, in hatcheries attempting to accelerate growth), both coho and chinook salmon undergo a reversion to parr condition (desmoltification) (Wedermeyer *et al.*, 1980 and references therein).

7.1.3 Temperature and migration - salmonids

Most studies on migratory behaviour of salmonids (*S. salar* and *S. trutta*) relate to spate rivers and indicate that upstream movement occurs at higher than average flows and when flows are increasing. Hellawell *et al.* (1974)[25] found that these generalities did not apply to a river with an equitable flow pattern, and that timing (season) was the main determinand, with details modified by changes in discharge, light intensity and temperature. They concluded that the greatest source of error in trying to identify and correlate causative factors was not knowing the availability of potential migrants at the seaward end.

Bishai (1960)[26] demonstrated that, within salmonid ecotypes, migratory fish were less thermally tolerant than lake or stream-dwelling ones.

Early this century, Ward (1927)[27] had observed that, when confronted with streams differing in temperature by 1°F (about 0.6°C), migrating salmon ascending rivers "selected" the stream with the lower temperature; this conclusion was made while unaware of the importance of other factors such as flow in stream selection. More recently, Major & Mignell (1966)[28] observed that adult *O. nerka* migrating up the Columbia River would not enter the Okagon River when the temperature of the latter exceeded 21°C.

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[23] Zaugg W.S., Adams B.L. & McLean L.R., 1972. Steelhead migration: potential temperature effects as indicated by gill adenosine triphosphatase activities. Science, 176; 415 416.

[24] Wedermeyer G.A., Saunders R.L. & Clarke W.C., 1980. Environmental factors affecting smoltification and early marine survival of anadromous salmonids. Marine Fisheries Review, 42; 1-14.

[25] Hellawell J.M., Leatham H. & Williams G.I., 1974. The upstream migratory behaviour of salmonids in the R.Frome, Dorset. Journal of Fish Biology, 6; 729-744.

[26] Bishai H.M., 1960. Upper lethal temperatures for salmonids. J. Cons. Int. Explor. Mer., 25; 129 133.

[27] Ward H.B., 1927. The influence of a power-dam in modifying conditions affecting the migration of the salmon. Proc. Nat. Acad. Sci. Wash., 13; 827-833.

[28] Major R.L. & Mignell J.L., 1966. Influence of Rocky Beach Dam and the temperature of the Okagon River on the upstream migration of sockeye salmon. Fishery Bulletin, 66 (1); 131-147.

Jonsson (1991)[29] showed that the initiation of downstream migration in salmonids (including Atlantic salmon and trout) was dependent on water temperature: as the temperature rose through 10°C the migration would begin. She lists many references which conclude either a threshold or a preferred temperature range for upstream spawning runs. Since activity at higher temperatures has a higher energetic cost, while lower temperatures conversely prohibit activity, the preferred range theory is the most accepted. Solomon (1978)[30] also correlated the migration of Atlantic salmon and sea-trout smolts to increase in water temperature. Jensen *et al.* (1989)[31] found Atlantic salmon adults unable to pass waterfalls in the River Vefsna, Norway, if water temperatures were below 8°C; Elson (1969)[32] found that river ascent by *S. salar* in the Northwest Miramichi River increased with increasing water temperature up to 24-25°C and then decreased towards 30°C (upper lethal temperature, see above). Hawkins (1989)[33] found that potentially upmigrating *S. salar* remained in the sea off the R. Dee, Scotland, when river water temperature exceeded 20°C.

Such temperature limitations have zoogeographic implications. Power (1981)[34] showed how climatic conditions down the eastern coast of North America result in temperature constraints on migration runs; the northernmost populations, in Quebec, had a small (1-2 months) midsummer window of opportunity for migration in late summer, other times of year being too cold; this "temperature window" widens further south, to some 6 months in Nova Scotia, until in Connecticut mid-summer temperatures in the river (and sea) are too high, resulting in two runs of stock, one early spring, one late autumn.

Conversely to the general impression that salmonids avoid heated water, Spigarelli & Thommes (1979)[35] concluded strong (albeit circumstantial) evidence for the attraction of *O. mykiss* to a thermal plume in Lake Michigan.

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[29] Jonsson N., 1991. Influence of water flow, water temperature and light on fish migration in rivers. Nordic J. Freshwater Res., 66; 20-35.

[30] Solomon D.J., 1978. Migration of smolts of Atlantic salmon (Salmo salar L.) and sea trout (Salmo trutta L.) in a chalk stream. Envir. Biol. Fish., 3; 223-229.

[31] Jensen A.J., Johnsen B.O. & Hansen L.P., 1989. Effect of river flow and water temperature on the upstream migration of adult Atlantic salmon Salmo salar L. in the River Vefsna, northern Norway. In: Brannon E. & Jonsson B. (Eds), Salmonid Migration and Distribution Symposium. Seattle, University of Washington; pp.140-146.

[32] Elson P.F., 1969. High temperature and river ascent by Atlantic salmon. Int. Council Explor. Sea., Report CM 1969/M:12; pp. 1-9.

[33] Hawkins A.D., 1989. Factors affecting the timing of entry and upstream movement of Atlantic salmon in the Aberdeenshire Dee. In: Brannon E. & Jonsson B. (Eds), Salmonid Migration and Distribution Symposium. Seattle, University of Washington; pp.101-105.

[34] Power G., 1981. Stock characteristics and catches of Atlantic salmon (Salmo salar) in Quebec, and Newfoundland and Labrador in relation to environmental variables. Can. J. Fish. Aquat. Sci., 38; 1601-1611.

[35] Spigarelli S.A. & Thommes M.M., 1979. Temperature selection and estimated thermal acclimation by rainbow trout (Salmo gairdneri) in a thermal plume. J. Fish. Res. Bd Canada, 36; 366-376.

Equally, a number of studies have been reported where a difference in temperature between two water bodies has had no effect on the migration of salmonids between the two (see Banks, 1969[36], for list).

7.1.4 Migration and heated discharges

Coutant (1968)[37] followed some 70 radio-tagged *Oncorhynchus* species in the Hanford reach of the Columbia River, where the Hanford nuclear reactor discharges a heated plume, and found that the adult fish mostly migrated upstream in shallow water on the opposite side of the river, avoiding any thermal barrier. However, Nakatani (1969)[38] found adult rainbow trout and chinook salmon up-migrating, and the latter spawning, towards the reactor side of the river.

He did find, from laboratory-based experiments, that the percentage mortality of chinook young increased with increased ΔT, as did their rate of growth; the temperature response appeared more related to absolute temperature than to the ΔT, "significant" (>20%) mortalities occurring at temperatures greater than 17°C. Down-migration of young occurred from March (fry and 0-group) to July (smolts); a lower ΔT on water temperatures at this time of year (of 6 to 15.5°C) together with the incidence of a yearly freshet (late May-early June) appeared to minimize any effects at that time. The ΔT from the reactors was "classified", but appears to have been up to 17°C.

The river is wide (*ca.* 500 m) and comparatively deep (about 12 m); the warmer, and therefore less dense, water would have been at the surface - other plants on large North American rivers show a drop of 8 to 10°C within 6-10 m of depth (e.g. Coutant, 1968[39]) - allowing spawning at the bed at ambient temperatures. Similarly, the constraint of the plume will lead to lateral differential temperature, allowing avoidance of the heated water by up-migrants on the opposite shore. However, Templeton & Coutant (1971)[40] observed that the route followed by most fish took them along the opposite bank from the reactors, but the same route was followed whether there was a

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[36] Banks J.W., 1969. A review of the literature on the upstream migration of adult salmonids. J. Fish Biol., 1; 85-136.

[37] Coutant C.C., 1968. Behaviour of adult salmon and steelhead trout migrating past Hanford thermal discharges. In: Thompson R.C., Teal P. & Swezea E.G. (Eds), Pacific Northwest Laboratory Annual Report, 1968, to U.S. AEC Division of Biology and Medicine, Vol.1. Richland, Washington, USA. pp. 9-10.

[38] Nakatani R.E., 1969. Effects of heated discharges on anadromous fishes. In: Krenkel & Parker, 1969. Chapter 10; 294-317.

[39] Coutant C.C., 1968. Behaviour of adult salmon and steelhead trout migrating past Hanford thermal discharges. In: Thompson R.C., Teal P. & Swezea E.G. (Eds), Pacific Northwest Laboratory Annual Report, 1968, to U.S. AEC Division of Biology and Medicine, Vol.1. Richland, Washington, USA. pp. 9-10.

[40] Templeton W.L. & Coutant C.C., 1971. Studies on the biological effects of thermal discharges from nuclear reactors to the Columbia River at Hanford. pp 591-614 In: Environmental aspects of nuclear power stations. Proceedings of Symposium, New York August 1970. 970pp. STI/PUB/261, International Atomic Energy Agency. Vienna.

discharge or not. When fish did come into contact with the effluent they would either swim through it or skirt round it. They concluded that:

> *"The uninhibited migration of salmon and trout past the reactors and the continued increase in size of the spawning populations near the reactors indicate that the reactor discharges have not adversely affected the environment for the fish species of most concern".*

Gray (1990)[41], studying tagged adult fish, similarly concluded no migratory block to upstream migration of these species by the thermal discharges on the Columbia River.

Johnsen (1980)[42] studied the movement of eight individual tagged migrating salmonids (*S. trutta, Oncorhynchus mykiss, O. tshawytscha* & *O. kisutch*) in a heated discharge plume (ΔT 10°C) in Lake Michigan. On release, fish in the discharge water moved at 0.2 m s^{-1} compared with speeds on leaving the vicinity of the discharge of 1 m s^{-1} (despite increased swimming speed with temperature, see above, Section 3), and showed frequent turning across the plume-ambient water interface (ΔT *ca* 5°C). Mean residence time in the plume was 13.08 h, equivalent to a loss of 37.7 km or *ca* 10 hours at normal migration speed (the maximum was 22 h for a *S.trutta*, equivalent to a loss of 63 km or 18 h). As the fish were caught within the plume, these data are minima; however, the results may well have been influenced by the handling stress of the tagging procedure, which is known to reduce swimming performance in fish (e.g. Turnpenny, 1983[43]), as well as by the influence of the relatively large acoustic or radio tags available at that time.

Since Johnsen (*loc. cit.*[44]) found a mean minimum residence time for trout in his effluent of 18.95 h, i.e. 1137 minutes (range 954 to 1320), the "concern level" of Alabaster (1967)[45] of 1000 minutes median lethal temperature (i.e. for 50% of fish) is particularly relevant; of course, 20% mortality might also be a valid cause for concern.

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[41] Gray R.H., 1990. Fish behaviour and environmental assessment. Environ. Toxicol. Chem., 9; 53-66.

[42] Johnsen P.B., 1980. The movements of migrating salmonids in the vicinity of a heated effluent determined by a temperature and pressure sensing radio telemetry system. In: Amlaner C.J. & MacDonald D.W. (Eds), A Handbook on Biotelemetry and Radio Tracking. Oxford, Pergamon Press; pp. 781-783.

[43] Turnpenny A.W.H., 1983. Swimming performance of juvenile sprat (Sprattus sprattus L.) and herring (Clupea harengus L.) at different salinities. J. Fish Biol., 23; 321-325.

[44] Johnsen P.B., 1980. The movements of migrating salmonids in the vicinity of a heated effluent determined by a temperature and pressure sensing radio telemetry system. In: Amlaner C.J. & MacDonald D.W. (Eds), A Handbook on Biotelemetry and Radio Tracking. Oxford, Pergamon Press; pp. 781-783.

[45] Alabaster J.S., 1967. The survival of salmon (Salmo salar L.) and sea trout (S. trutta L.) in fresh and saline water at high temperatures. Water Research, 1; 717-730.

Gray *et al.* (1977)[46] during experimental studies found that juvenile chinook salmon avoided a simulated thermal effluent when the ΔT was of 9-11°C; none of their fish passed through plumes of absolute temperature ≥ 24°C. After repeated trials, avoidance conditioning was invariable at "higher plume temperatures", the fish not approaching the discharge.

Appendix 2 - Background information on the thermal tolerance of North American fish

Fish gain heat quite rapidly by conduction across their entire body surface. Moreover, they must pass water over their gills in considerable volumes, since the concentration of oxygen in river water is comparatively low. Gills are richly supplied with blood and have a substantial surface area to optimize gas exchange. These features also make for efficient heat exchange and the blood rapidly distributes heat throughout the body (Crawshaw, 1979[47]). They therefore rapidly pick up heat from the water when they enter artificially heated water.

The response of fish to temperature is complex. Fish have natural thermal niches (preferenda) and in the temperate zone freshwater species are either:

- cold water species, such as salmon, trout, tomcod & smelt;
- cool water species;
- warm water species, such as carp;

This categorization tends to fall along taxonomic lines, in that related species and genera have similar thermal niches (Hokanson, 1977[48]). Cherry *et al.* (1975)[49] found that the stenothermal salmonids had the narrowest temperature tolerance ranges of all the teleosts which they studied.

Superimposed upon this thermal selectivity are temporal variations in preferenda that can be correlated with the age or developmental stage of the fish, its physiological condition, or with various environmental variables. Young fish generally have higher thermal preferences and greater tolerances than do older fish. Feeding activity, reproductive or migratory behaviour and stress (anoxia, turbidity, salinity changes and chemical pollutants) might substantially alter normal thermal responses.

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[46] Gray R.H., Genoway R.G. & Barraclough S.A., 1977. Behaviour of juvenile chinook salmon (Oncorhynchus tshawytscha) in relation to simulated thermal effluent. Trans. Am. Fish. Soc., 106; 366 370.

[47] Crawshaw L.I., 1979. Responses to rapid temperature change in vertebrate ectotherms. American Zoologist, 19; 225-237.

[48] Hokanson K.E.F., 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. Journal of the Fisheries Research Board of Canada, 34; 1524-1550.

[49] Cherry D.S., Dickson K.L. & Cairns J. Jr, 1975. Temperatures selected and avoided by fish at various acclimation temperatures. J. Fish. Res. Bd Canada, 32; 485-491.

For any fish there are temperatures that it prefers, temperatures to which it can acclimate, temperatures that it would seek to avoid but at which it can survive for various periods of time, and temperatures that are lethal. Moreover, the ability of individuals to survive is not the same as the ability of the species to continue to prosper; increased temperatures may advance or delay breeding seasons, encourage breeding in the wrong place, or inhibit fish migration.

Indirect effects of temperature on fish include reduced solubility of gases, particularly of oxygen, an effect which can be exacerbated by the elevated temperature simultaneously increasing the rate of oxygen removal by pollutants such as sewage. The sort of temperature elevations that are encountered outside the immediate vicinity of a power station discharge are of between 1° and 3°C, which would decrease the solubility of oxygen by about 0.5 ppm.

The effects of temperature on the biology and ecological requirements of fish have been extensively studied and reviewed. Temperature can affect survival, growth and metabolism, activity, swimming performance and behaviour, reproductive timing and rates of gonad development, egg development, hatching success, and morphology. Temperature also influences the survival of fishes stressed by other factors such as toxins, disease, or parasites. Many of these effects will occur well below the upper lethal temperature which is given below.

The published information on the temperature requirements of freshwater fishes is found in thousands of documents. It is convenient that several authors have condensed this information into reviews of the literature. The general reviews of fisheries biology by Carlander (1969[50], 1977[51]) and Scott and Crossman (1973)[52] include some temperature data. Several reviewers have focussed on thermal biology, specifically: lethal and/or preference temperatures (Coutant 1977a[53]; Cherry *et al* 1977[54]; Kowalski *et al* 1978[55]; Houston 1982[56]). Others have widened their reviews to include data on

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[50] Carlander, K.E. 1969. Handbook of Freshwater Fishery Biology. Volume One. 3rd edition. Iowa State University Press, Ames, Iowa 752 p.

[51] Carlander, K.E. 1977. Handbook of Freshwater Fishery Biology. Volume Two. Iowa State University Press, Ames, Iowa 431 p.

[52] Scott, W.B. and E.J. Crossman. 1973. Freshwaster Fishes of Canada. Bulletin 184. Fisheries Research Board of Canada, Ottawa 966p.

[53] Coutant, C.C. 1977a. Compilation of Temperature Preference Data. J. Fish. Res. Board Can. 34:739-745

[54] Cherry, D.S., K.L. Dickson, J. Cairns Jr., and J. R. Stauffer, 1977. Preferred, Avoided and Lethal Temperatures of Fish During Rising Temperature Conditions. J. Fish. Res. Board. Can. 34:239-246.

[55] Kowalski, K.T., J.P. Schubauer, L.L. Scott and J.R. Spotila, 1978. Interspecific and Seasonal Differences in the Temperature Tolerance of Stream Fish. J. Thermal Biol. (3) 105-108.

[56] Houston, A.H. 1982. Thermal Effects Upon Fishes. Report NRCC No. 18566. National Research Council of Canada. Associate Committee on Scientific Criteria for Environmental Quality. 200p.

growth, preference and lethal temperatures (Leidy and Jenkins 1977[57]; McCauley and Casselman 1980[58]; Jobling 1981[59]). Comprehensive reviews on the whole range of temperature requirements for fishes (i.e., lethal, preference, growth, reproductive) were given by EPA (1974)[60] and Brown (1974)[61].

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[57] Leidy, G.R. and R.M. Jenkins, 1977. The Development of Fishery Compartments and Population Rate Coefficients for Use in Reservoir Ecosystem Modelling, Final Report - June 1977. Contract Report 4-77-l. Office, Chief of Engineers, U.S. Army, Washington, D.C. by USDI Fish and Wildlife Service, National Reservoir Research Program, Fayetteville, Ark. 225p.

[58] McCauley, R.W. and J.M. Casselman 1980. The Final Preferendum as an Index of the Temperature for Optimum Growth in Fish. United Nations Food and Agriculture Organization, European Inland Fisheries Advisory Commission, Symposium 80/E76, Rome, Italy pp83-93.

[59] Jobling, M. 1981. Temperature Tolerance and the Final Preferendum - Rapid Methods for the Assessment of Optimum Growth Temperatures. J. Fish Biol. 19:439-455.

[60] EPA 1974. 316(a) Technical Guidance - Thermal Discharges. Draft. September 30, 1974. Water Planning Division, Office of Water and Hazardous Materials, Env. Prot. Agency 187p

[61] Brown, H.W. 1974. Handbook of the Effects of Temperature on Some North American Fishes. American Electric Power Service Corp., Canton, Ohio. 524 p and App (12).

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PRESENT POSITION

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ACADEMIC QUALIFICATIONS AND POSITIONS

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)

Senior Research Associate, Dept., of Zoology, University of Oxford.

Visiting Research Fellow, University of Southampton.

EXPERTISE AND EXPERIENCE

An ecological consultant and research scientist with 30 years experience combining theoretical, applied and field research. Extensive experience of the management of major ecological assessment projects including preparation and presentation of material for public enquires and liaising with conservation bodies and engineers. Projects undertaken include conservation planning for large tropical nature reserves, ecological effects studies of nuclear power station intakes, conservation studies of rare freshwater life and effects of climate change and drought. I lecture and hold a position as a senior research associate in the department of Zoology, University of Oxford.

PROJECT INVOLVEMENT

INDUSTRIAL ECOLOGY

Wide experience in power plant cooling water engineering including the preparation and presentation of evidence at public inquires and the writing of environmental impact assessments. Studies in the USA for Riverkeeper have included work on the effectiveness of Gunderbooms for minimising entrainment, analysis of the DEIS for Indian Point, Bowline 1, 2 & 3, Lovett, Roseton and Albany power plants. Work for the Natural Resources Defence Council include assessment of the impact of the Astoria Repowering Project in New York. Considerable recent experience working on fisheries issues linked to power plant proposals in the Hudson

River, New York and Morro Bay, California. Extensive work has been carried out for Riverkeeper on the US Environmental Protection Agency's (EPA) 316b legislation on cooling water intakes.

Project management of major UK environmental impact studies including Sizewell B , Hinkley C and Fawley B power stations, the Severn tidal barrage scheme and the Usk Barrage. Other projects have included marina developments and ecological issues of importance to ports. I have acted as a fish and fisheries expert witness on the London Gateway Project for Pacific & Orient Shipping Company with respect to the London Gateway port proposal and as an advisor for the Bristol Port Company. I have also acted as an expert witness on the effects of aggregate dredging and the effects of outfalls on salmon movement.

A particular area of expertise is on the impingement and entrainment of fish and crustaceans at coastal and estuarine intakes in the British Isles. I have worked on this field for more than 26 years and hold the largest data set on impingement of fish in existence.

TROPICAL ECOLOGY

Fisheries research 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.

ECOLOGICAL STUDIES

BRITISH ESTUARINE AND RIVERINE COMMUNITIES

More than 26 years of study of British estuarine fish and crustacean population dynamics. Studies undertaken of community dynamics, wood webs, climatic effects and predator-prey interactions. Recent work has concentrated on the effects of climate change on fish. I have particular expertise in the Bristol Channel/ Severn Estuary and the Thames Estuary.

CONSERVATION MANAGEMENT PLANNING

Wide range of projects undertaken including a senior 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.

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.

BIOLOGICAL AND STATISTICAL SOFTWARE

The designer and developer of computer based expert systems, including the commercial software packages E3 (for environmental effects evaluation which is available from The Stationary Office), Species Richness and Diversity (available from PISCES), Community Analysis Package (available from PISCES) and Dynamica (available from Chapman & Hall). I designed and developed PISCES, an expert system used to predict fish and crustacean impingement and entrainmnet at power station intakes. Most recently, I designed and wrote with Dr Richard Seaby QED Statistics, which is a general statistic package.

POPULATION BIOLOGY

Including the study of fish, ostracod, crustacean and insect populations in many diverse habitats. I lecture in population dynamics at the University of Oxford. I published with Sir Richard Southwood on long-term changes in insect populations.

LECTURING AND WRITING

LECTURER AND SUPERVISOR

An experienced supervisor of post-graduate students. Lecturer and tutor on the climatic change masters coarse at the University of Oxford.

WRITING AND BROADCASTING

Freelance writer for British Wildlife and other magazines. Occasionally working as a scientific advisor for the BBC and other television companies. Lecturer to natural history clubs and societies on rain forests, tropical fish and British wildlife.

PROFESSIONAL HISTORY

Present positions: Director PISCES Conservation Ltd. & Senior Research Associate, Dept. of Zoology, University of Oxford

Employer : Department of Zoology, University of Oxford.
Position : Senior 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 modelling, 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 modelling of water movement and cooling water discharges: (iii) the causes of red tides: (iv) freshwater community structure in relation to water chemistry changes caused by acid rain.

OTHER POSITIONS HELD

2008- Assistant editor Journal Marine Biological Association of the United Kingdom.

1998-2001 Council of the Fisheries Society of the British Isles.

1984-1990. Assistant editor of the Journal of Fish Biology

1987 – 2001. 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.

EXTERNAL PUBLICATIONS

BOOKS

Henderson & Margetts (Eds), 1989. Fish in Estuaries. Fisheries Society of the British Isles.

Henderson (1990). *Freshwater ostracods*. Synopsis of the British Fauna (New Series) No. 42. Universal book services, Oegstgeest, Netherlands.

Henderson, P. A. & Southwood, T. R. E. (2000) *Ecological Methods*. 3rd Edition Blackwell Scientific. 590 pp

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Speight, M **& Henderson , P.**A. (2010) *Marine Biology: Concepts and Applications*. Wiley-Blackwell, 256 pp.

PAPERS

Hamilton, **Henderson** & Moran (1981). Fluctuation of environment and convolved antagonist polymorphism as factors in the maintenance of sex. Natural selection and social behaviour: recent research and new theory. Chiron press. New York.

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Bamber,Glover, **Henderson** & Turnpenny (1983). Diplostomiasis in the sand smelt population at Fawley Power Station. J. Fish Biol. 23, 201-210.

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Bamber & **Henderson** (1983). Epifaunal arthropods from tide pools at Rhosneiger. Porcupine Newsletter 2, 196-199.

Henderson & Whitehouse (1984). The growth and mortality of larval herring *Clupea harengus* L in the Blackwater estuary, Essex. J. Fish Biol. 24, 613-622.

Henderson, Turn penny & Bamber (1984). Long-term stability of a sand smelt population subject to power station cropping. J. Appl. Ecol. 21, 1-10.

Bamber & **Henderson** (1985). Morphological variation in British Atherinids, and the status of *Atherina presbyter* Cuvier (Pisces: Atherinidae). Biol. J. Linn. Soc. 25, 61-76.

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