State of Maryland Perspectives on Cooling Water Intake Technologies to Protect Aquatic Organisms

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Abstract: Maryland is a state to which the U.S. Environmental Protection Agency (EPA) has delegated authority to administer the National Pollutant Discharge Elimination System (NPDES). In the late 1970's the state developed and implemented regulations for cooling water withdrawal and intakes in accordance with EPA guidance on implementation of Clean Water Act Section 316b provided at that time. The Code of Maryland Regulations (COMAR), 26.08.03.04-05, established procedures for determining adverse environmental impacts due to impingement and entrainment at cooling water intake structures (CWIS) relative to determination of best technology available (BTA) for minimizing these impacts. Maryland has applied these regulations to all power plants in Maryland that operate CWIS, including facilities located on both freshwater and estuarine waters. Over the past 30 years, the Power Plant Research Program (PPRP) of the Maryland Department of Natural Resources (MdDNR), has participated in or conducted studies of a wide range of technologies and processes including, for example, wedgewire screens, modifications to intake structures, Royce "Smooth Tex" intake screens, altered plant operations (e.g., screen rotation times), and installation of barrier nets. These evaluations resulted in a range of determinations, from deciding whether an existing CWIS already featured BTA to requiring installation of tested technologies at some facilities. Our 30 years of experience supports our contention that there is no single technology or suite of technologies that can be applied on a state-wide or national basis. However, we believe it is important to have a consistent national process for identifying BTA at the site-specific level.

Introduction

Maryland facilities that utilize cooling water intake structures (CWIS) are regulated by the Maryland Department of Environment (MDE), the state agency with authority and responsibility for National Pollutant Discharge Elimination System (NPDES) permitting, as delegated by the U.S. Environmental Protection Agency (EPA). Maryland's regulations relating to CWIS were developed based on EPA guidance on implementation of Clean Water Act Section 316b when that legislation was enacted in 1972, and are documented in the Code of Maryland Regulations (COMAR), 26.08.03.04-05. These regulations address all potential impact sources associated with withdrawal of cooling water, including entrainment and impingement. While MDE is responsible for regulation of CWIS, a sister agency, the Maryland Department of Natural Resources (MdDNR), provides the technical support employed to address CWIS impacts at power plants.

MdDNR's Power Plant Research Program (PPRP) was established in 1971 to ensure that Maryland meets its electricity demands at reasonable costs while protecting the State's valuable natural resources. It provides a continuing program for evaluating electricity generation issues and recommending responsible, long-term solutions. The Maryland legislature created the Power Plant Siting Program, precursor to the current PPRP, in 1971 as a result of extensive public debate regarding the potential effects on the Chesapeake Bay from the Calvert Cliffs Nuclear Power Plant. Calvert Cliffs was a source of concern because the plant uses a once-through cooling system that withdraws 3.5 billion gallons of water per day from the Bay and discharges the water back to the Bay with a temperature elevation of about 12° F. The controversy over potential environmental impacts during the licensing of Calvert Cliffs prompted the creation of PPRP to ensure a comprehensive, technically based evaluation and resolution of environmental and economic issues before decisions were made regarding whether and where to build other generating facilities. Today, PPRP continues to play this role in providing a comprehensive set of technically based licensing recommendations for proposed generating facilities. PPRP also conducts research on power plant impacts to the Chesapeake Bay, one of Maryland's greatest natural resources, and provides technical support to MDE regarding all power plant NPDES permits and variances associated with those permits. In addition to surface water concerns, PPRP's evaluations consider impacts to Maryland's ground water, air, land, and human resources.

PPRP operates with a small administrative and technical staff, supported by contractors with special expertise in engineering, economics, biology/ecology, and atmospheric sciences. The program is funded from an Environmental Trust Fund that is maintained through a surcharge on users of electricity. The surcharge amounts to about 25 cents per month for average residential customers, and has provided a relatively stable source of funding to address the State's power plant assessment needs for nearly three decades. The manner in which PPRP carries out its responsibilities with regard to CWIS assessments is varied and customized to address issues and circumstances specific to individual facilities and impacts. As a result of review of a permit or variance application from a given facility, PPRP may recommend CWIS studies be performed by the applicant. In such instances, PPRP utilizes its contractors to conduct technical reviews, the product of which provides support for recommendations from PPRP to MDE concerning disposition of the applicant's application and compliance with COMAR. In cases where an issue may be relatively generic and findings may be relevant to broader state-wide issues, PPRP may develop cooperative CWIS studies with an applicant, with PPRP contractors working with the applicant and their consultants to develop and implement studies. In cases where potential impacts are of concern, or where the efficacy of new technologies may be of interest, PPRP may conduct independent CWIS studies. Since inception of the program, PPRP has carried out all of these modes of study at all power plants in Maryland with regard to cooling water intake impacts and structures. Findings from a number of these studies are presented in this paper and provide the basis for the State's perspective on CWIS impact assessment methodologies, significance and solutions.

Maryland's General CWIS Perspective

Thirty years of experience in assessing and resolving CWIS impact issues serve as the basis for Maryland's underlying perspective. The first major aspect of this perspective is that CWIS issues are not simply technology/structural issues. While CWIS may stand for "cooling water intake structure," many factors, beyond simply the structure, influence the biological consequences of the operation of a CWIS. Location of the CWIS is critical, both in terms of ecosystem (e.g., fresh water river versus low salinity estuarine waters) and site characteristics (e.g., intake flush with shoreline versus long, dredged intake canal). The mode of operation of the CWIS is also very important, particularly in influencing the extent of mortality of organisms that may be affected by the CWIS. For example, the frequency of intake screen rotation and washing can have a significant effect on the level of mortality that is imposed on impinged fish. Similarly, the strength of the screen washing water stream, and the location at which impinged fish may be returned to the source water body can similarly impact the resulting mortality rate. The major point here is that CWIS impacts, and the means of minimizing those impacts, must be viewed holistically; taking into account the intake hardware, its mode of operation, and the site-specific characteristics of the ecosystem on which the CWIS effects are exerted. Such a perspective precludes simple solutions such as standardized technology applications and requires site-specific assessments and considerations. In the remainder of this paper, I describe a number of types of studies that have been done and actions that have been taken to reduce CWIS impacts throughout Maryland over the past 30 years, and provide examples to illustrate how the evolution of diverse actions taken at various power plants have resulted in significant CWIS impact reductions or resource enhancements. Figure 1 shows the locations of power plants in Maryland, with three plants that will be addressed below highlighted: Chalk Point, Calvert Cliffs, and Morgantown.

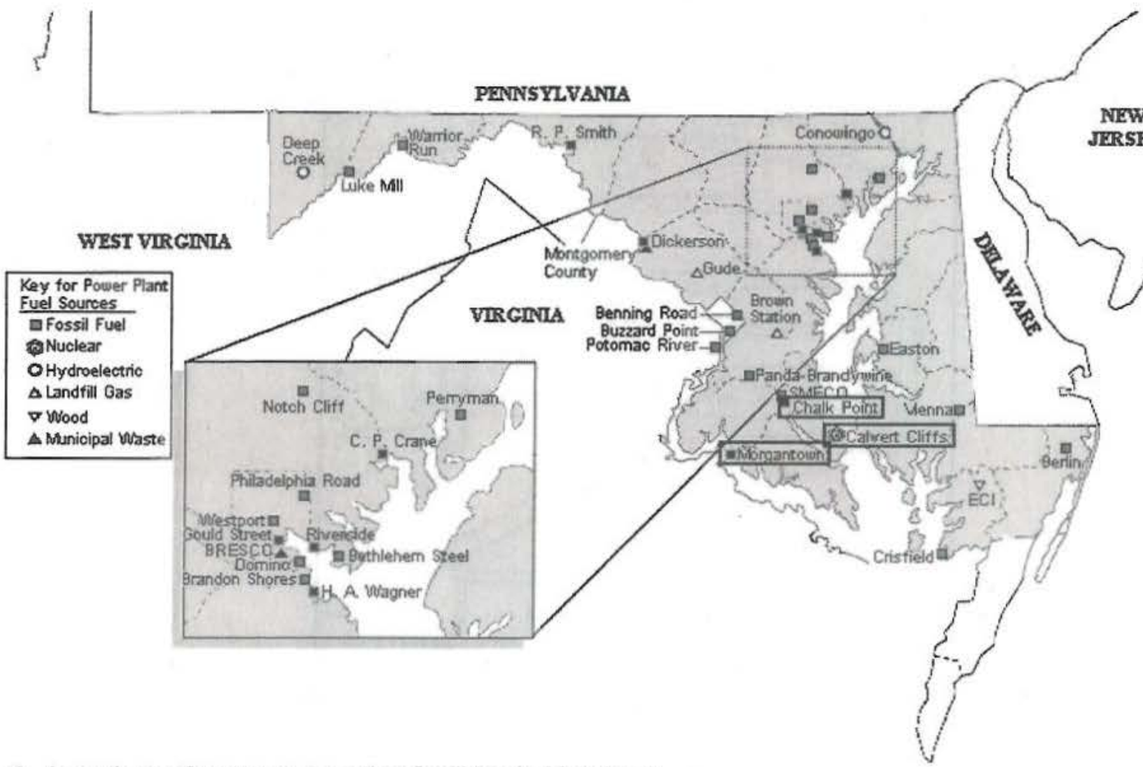

Figure 1. Locations of power generating facilities in Maryland.

Chalk Point Steam Electric Station

The Chalk Point Steam Electric Station (SES), owned by Mirant Energy (formerly PEPCO), is located on the estuarine portion of the Patuxent River in Prince George's County. It is the largest generating facility in Maryland, with a total generation capacity of 2,415 MW provided by a mix of oil, coal and gas generating facilities. Units 1 and 2 utilize a once-through cooling system, withdrawing a maximum of 250,000 gal/min per unit from and discharging the heated water into the Patuxent River. Units 3 and 4 have closed-cycle cooling, using natural draft cooling towers and re-circulating water at a rate of 260,000 gal/min per unit, with make-up and blow-down taken from and discharged into the intake and discharge streams of the once-through cooling system. Seven combustion turbine generators are also located on the site. The plant has dredged intake and discharge canals, as seen in Figure 2. One feature of the cooling water system to note in Figure 2 is the location of what are termed auxiliary cooling pumps. These pumps shunted water from the intake canal directly to the discharge canal as a means of ensuring compliance with a 100° F maximum temperature of waters discharged to the Patuxent River.

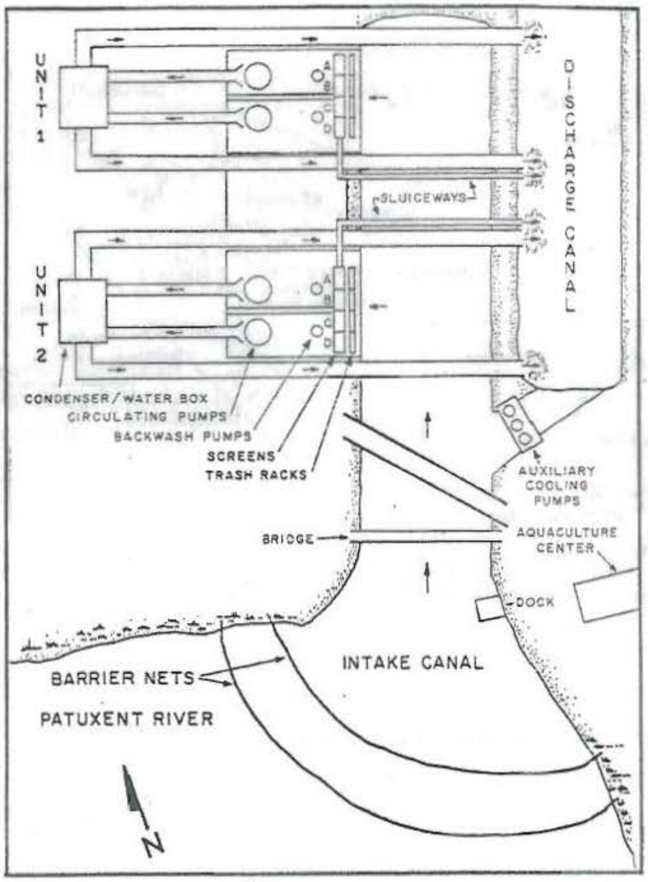

Figure 2. Plan view diagram of the Chalk Point SES, showing the configuration of the intake canal, cooling system, and discharge canal; note the location of the auxiliary cooling pumps.

When Chalk Point first began operating in 1964, a number of potentially significant biological impacts became evident. Large numbers of fish and crabs were being impinged, with potential for adverse biological impacts in addition to causing significant operational difficulties (e.g., small crabs were carried over the traveling screens and then blocked condenser tubes, requiring plant shutdowns for cooling system clean-up). Extensive on-going monitoring studies revealed the potential for other sources of significant impacts (MMES 1985). The three primary areas of concern identified by PPRP included: mortality of fish and crabs entrained through the auxiliary cooling pumps, primarily due to physical damage; impingement of fish and crabs on CWIS traveling screens; and, significant entrainment of forage fish, specifically bay anchovy. The manner in which these issues were addressed and resolved are illustrative of Maryland's approach to resolving CWIS issues.

Tempering pump entrainment - Auxiliary cooling water pumps, also called tempering pumps, were not screened. Thus, when operated, all ages and sizes of fish and crabs could be passed through the pumps and suffer physical damage from striking pump impellors and experiencing pressure changes. Large concentrations of fish and crabs were present in the intake canal, most likely because the intake flows and configuration of the canal were attractive to these organisms, which resulted in large numbers of organisms being entrained through the pumps. PPRP carried out a detailed assessment of the effectiveness of the tempering pumps for reducing plant-induced mortality of aquatic biota, using data collected by the facility owner and their contractors (Cadman and Holland, 1986). Several Representative Important Species (RIS) and dominant benthic and zooplankton species were used in the evaluation as indicators of overall system-wide responses. Expected mortality with and without auxiliary pump operation was estimated using thermal tolerance data available from the literature for blue crabs, white perch, striped bass, spot, *Macoma balthica* (a shellfish), and *Acartia tonsa* (a zooplanktor). PPRP concluded that the operation of the pumps increased plant-induced mortality of spot, white perch, striped bass, and zooplankton, but could reduce blue crab mortality slightly under some circumstances. *Macoma* mortality was largely unaffected by their operation. The overall conclusion was that cessation of use of the tempering pumps would result in a 50% decline in losses of fish and crabs from CWIS operations. A sensitivity analysis confirmed that the conclusions drawn were not significantly affected by uncertainties in the input data used. As a result of this evaluation, PPRP recommended to MDE that the Chalk Point NPDES permit be modified to eliminate the requirement for use of auxiliary pumps. Thermal criteria in the permit were later changed to a thermal loading cap rather than a specific discharge temperature cap.

CWIS Traveling Screen Impingement – As noted above, impingement rates at the Chalk Point facility were very high when the facility first began operation, with on the order of 2 million fish and 2 million crabs being impinged annually (Figure 3). The primary factor contributing to these high impingement rates was the apparent attractiveness of the intake canal to both fish and crabs, with the result that high densities of organisms would regularly occur in front of the intake screens. Chalk Point consulted with PPRP on means of reducing impingement that would have costs within the limits specified in Maryland's CWIS regulations (BTA is defined in Maryland regulations as being CWIS modifications the cost of which would be less than five times the value of the organisms lost to impingement). Because the cause of the high impingement was the high densities of organisms in the intake canal, the first feasible method tested was the deployment in 1981 of a single, 1.25-inch stretch mesh barrier net at the intake canal entrance, that would prevent organisms from moving into and concentrating in the canal. Deployment of this net reduced impingement by more than 75% (Figure 3), but did not resolve some of the operational problems. In particular, small crabs continued to occur in the intake canal in high abundances. Thus, in 1984, a second, smaller mesh net (0.75-inch stretch mesh) was deployed behind the first net, net supports and anchors were modified, and the manner in which the net was deployed was changed. These modifications resulted in further declines in impingement rates, with a total reduction of about 90% (Figure 3) (Loos, 1987). More detailed documentation of the Chalk Point barrier net studies can be found in the paper by David Bailey of Mirant Energy in this volume.

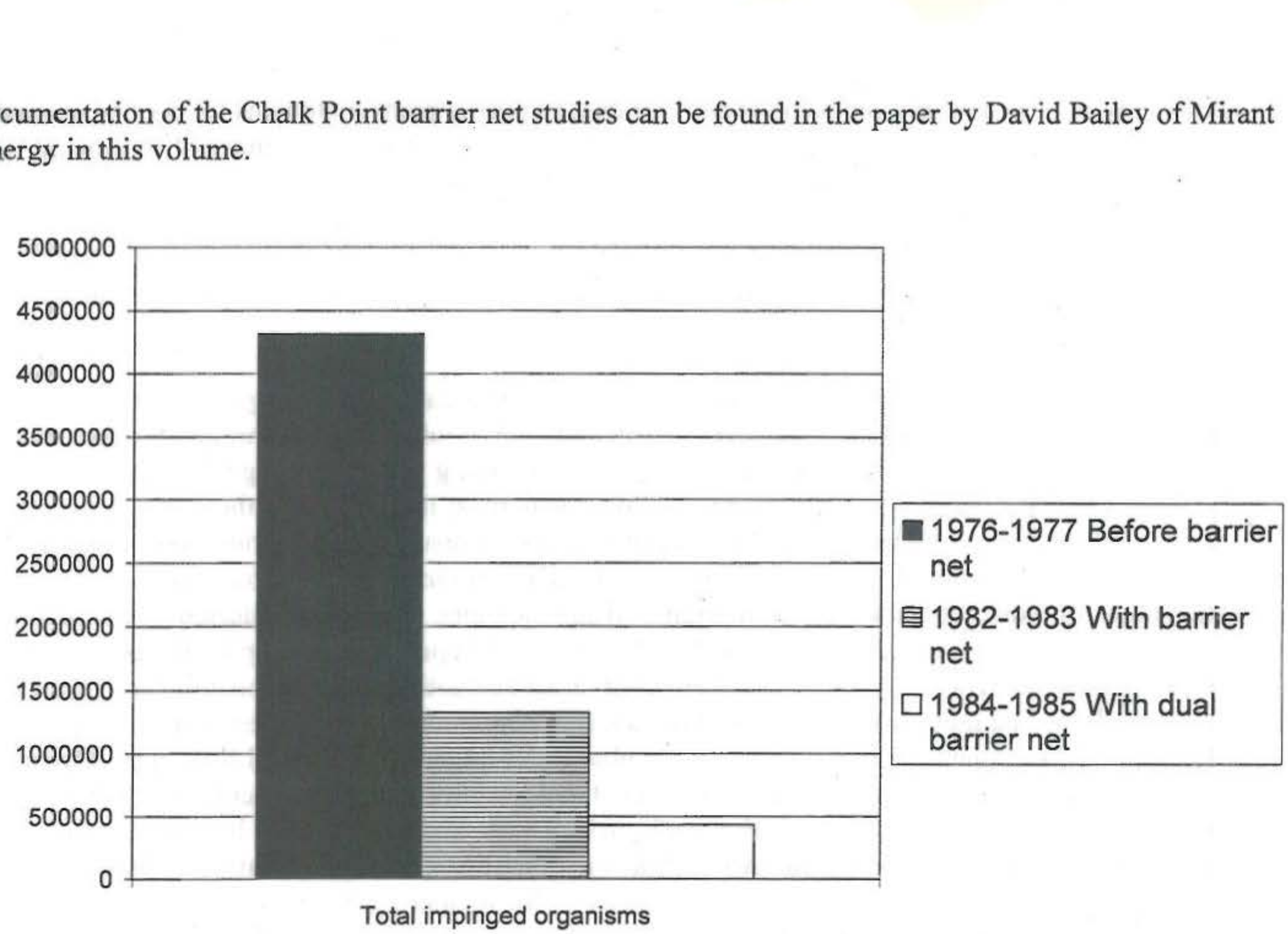

Figure 3. Average annual total number of fish and crabs impinged at the Chalk Point SES prior to installation of a barrier net (1976-1977), after installation of a single 1.25 in mesh barrier net (1982-1983), and after installation of a double barrier net system, with 1.25 in and 0.75 in mesh (1984-1985).

Bay anchovy entrainment – PPRP assessments of biological impacts at Chalk Point included extensive modeling to quantify the effects of entrainment on the Patuxent River ecosystem (MMES 1985). Using hydrodynamic modeling and field data on ichthyoplankton densities and distributions, PPRP estimated that as much as 76% of the Patuxent River bay anchovy stock was being lost to the ecosystem as a result of entrainment mortality. Bay anchovy is a forage fish of great value to recreationally and commercially important predator species in the river. PEPCO consultants conducting independent modeling concluded that entrainment losses were only as high as 25%. Many factors contributed to the divergent modeling results, with no clear means of firmly establishing which estimate was most reliable or realistic. Given the potential significance of entrainment losses of this magnitude, PPRP concluded that it was appropriate to investigate the feasibility of intake technologies that could reduce entrainment at Chalk Point. Thus, PPRP initiated studies of wedge-wire screens at an in-situ testing facility at the plant. PEPCO cooperated in the study by providing on-site testing locations and a variety of support. Details of the testing methods and procedures can be found in Weisberg et al. (1987). The exclusion efficiency of cylindrical wedge-wire screens was investigated by measuring entrainment of larval bay anchovy and naked goby through screens with slot sizes of 1, 2 and 3 mm, and through an unscreened intake, with the screens mounted on a barge moored in the Chalk Point intake canal (Figure 4). The degree of exclusion by the screens increased with fish size. Fish less than 5 mm were not excluded by any of the screens, while ichthyoplankton larger than 10 mm were excluded by screens of all slot sizes (Weisberg et al., 1987). While the screens were confirmed

wedge-wire screens

to have the capability for significantly reducing entrainment, issues arose concerning the potential for screen fouling and corrosion in an estuarine environment, and the high cost of employing fine mesh screens for intake volumes as large as those at Chalk Point. The questionable feasibility for successful deployment of this technology at this facility, and disagreement on the magnitude of the entrainment problem, led to negotiations between PPRP and PEPCO on alternative resolutions of the entrainment issue. The outcome of these negotiations was an agreement, incorporated into the Chalk Point NPDES permit, on fisheries enhancements that would serve as out-of-kind mitigation for the entrainment impacts. PEPCO was required to implement several different enhancement projects, including removal of barriers to anadromous fish migration in tributaries to the Patuxent River, and implementing an aquaculture program to produce striped bass, yellow perch, and American shad for stocking in the river. Maryland DNR believes that the gradual recovery of stocks of these species in the Patuxent River over the past 20 years has been enhanced as a result of this mitigation program.

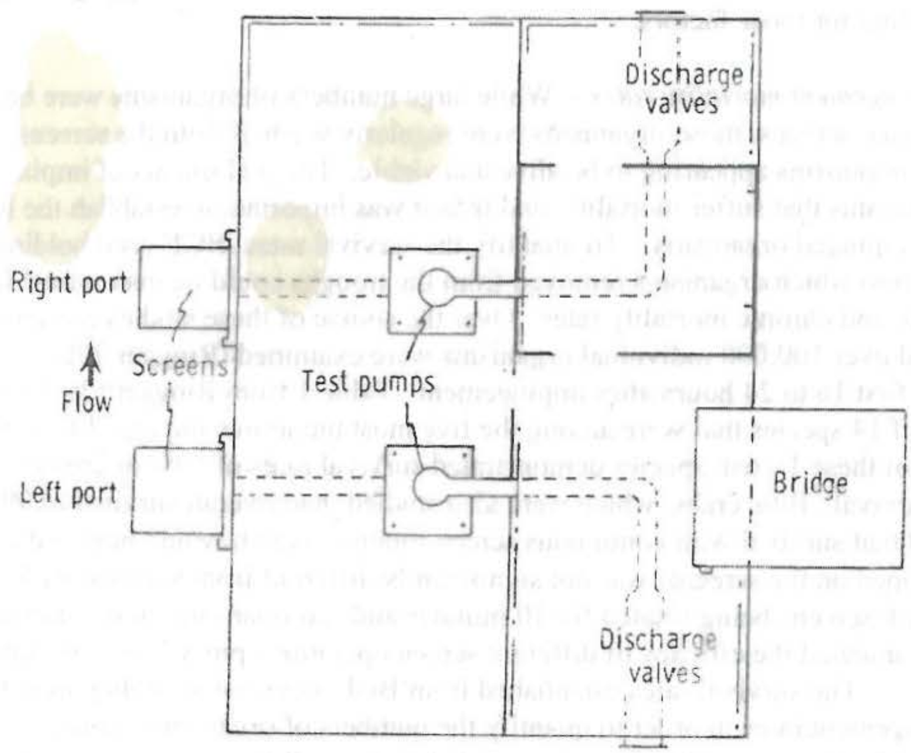

Figure 4. Plan view diagram of the PPRP wedge-wire *in –situ* testing barge; water was withdrawn through test screens and samples collected at the pump discharge points.

Calvert Cliffs Nuclear Power Station

Calvert Cliffs is owned by Constellation Nuclear, a member of Constellation Power Source, Inc., (formerly Baltimore Gas and Electric Company, BGE). Maryland's only nuclear power plant, it is located on the Chesapeake Bay mainstem in Calvert County. It has a generating capacity of 1,675 MW, and employs a once-through cooling system utilizing 2.5M gpm. It has a shoreline intake embayment with a curtain wall that extends 8.5 m below the surface, and a 1,460 m long, 15.5 m deep dredged intake channel from the curtain wall to the main channel of the Bay. Units 1 and 2 began operating in May 1975 and April 1977, respectively.

Because of it's size and the extent of controversy surrounding its location and construction, Calvert Cliffs was the subject of intense scrutiny and environmental assessment. Utility contractors conducted a wide range of intense environmental studies to satisfy Nuclear Regulatory Commission license technical specifications. These utility studies were augmented by extensive PPRP-funded studies. All of these studies and their findings are described in detail in MMC (1980), which summarized PPRP's conclusions regarding biological impacts of Calvert Cliffs. At this facility, impingement of fish and crabs was the issue of greatest concern. When the plant first began operating, very large numbers of both fish and blue crabs, often more than 1 million annually, were impinged (Figure 5; data from Ringger, 2000). At issue to PPRP was whether this magnitude of impingement would have an adverse impact on fish and blue crabs stocks within Chesapeake Bay. This issue was addressed in a number of ways, three of which are discussed here: evaluation of species-specific mortality rates due to impingement; investigation of alternative intake technologies to reduce entrainment and/or impingement; and, assessment of factors causing impingement and means of mitigating for those factors.

Species-specific impingement mortality rates - While large numbers of organisms were being impinged on the 9.6 mm mesh intake screens, those organisms were regularly washed from the screens and returned to the Bay, with many organisms appearing to be alive and viable. The real impact of impingement is a consequence of organisms that suffer mortality, and thus it was important to establish the level of mortality experienced by the impinged organisms. To quantify the survival rates, BGE used holding tanks along the screen wash trough into which organisms removed from the troughs could be maintained for 48 hours to determine immediate and chronic mortality rates. Over the course of these studies conducted from 1975 to 1981, 57 species and over 100,000 individual organisms were examined (Ringger 2000). Most mortality occurred within the first 16 to 24 hours after impingement. Table 1 from Ringger (2000) presents the 48-hour survival rates of 14 species that were among the five most numerous impinged fish species in any single year. Eleven of these 14 fish species demonstrated survival rates of 50% or greater, with 5 exhibiting greater than 90% survival. Blue crabs, which were also studied, had overall survival of 99.5%. These studies also showed that survival with continuous screen rotation, which would have reduced the time that organisms were trapped on the screens, was not significantly different from survival with normal screen wash operations, with screens being rotated for 10 minutes and stationary for 50 minutes of each hour. Thus, the study documented the efficacy of different screen operations procedures for minimizing impingement impacts. The survival rates established from BGE's extensive studies were then applied by PPRP to total impingement rates in order to quantify the numbers of organisms actually being lost to the Chesapeake Bay ecosystem as a result of impingement at Calvert Cliffs.

Table 1. Average percent survival of the fourteen fish species that were among the five most numerous impinged fish species in any single study year; survival was based on fish condition in holding pools 48 hours post impingement (from Ringger 2000)

Most Common Species	Percent survival
Blueback herring	47
Bay anchovy	68
Atlantic menhaden	52
Weakfish	38
Threespine stickleback	91
Skilletfish	93
Spot	84
Atlantic silverside	54
Atlantic croaker	19

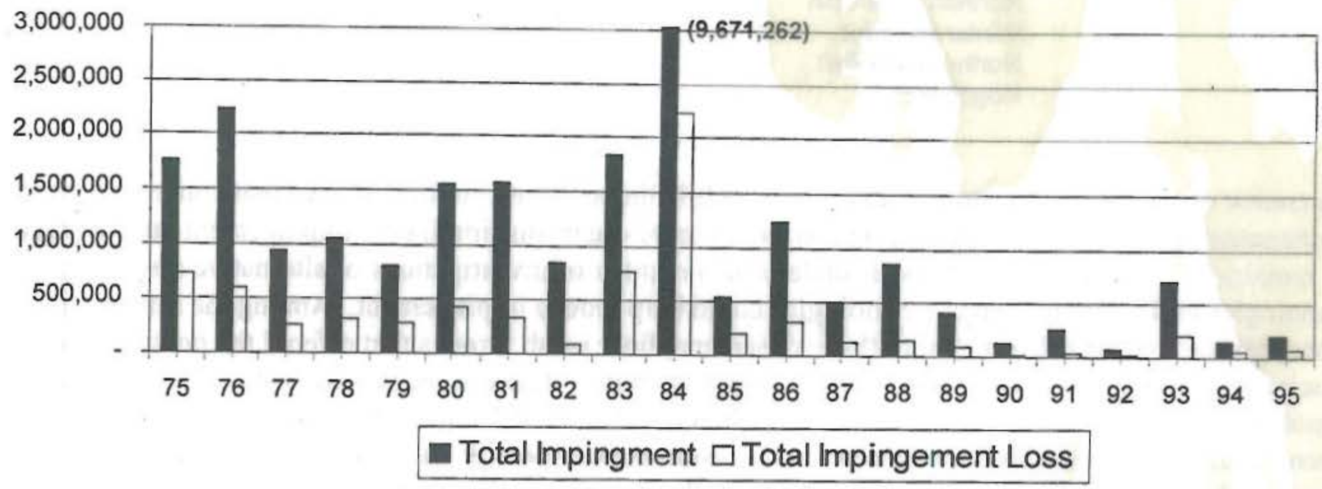

Figure 5. Annual fish impingement and fish lost to impingement at the Calvert Cliffs nuclear power plant (data from Ringger 2000)

Morgantown Steam Electric Station

The Morgantown SES, located on the estuarine portion of the Potomac River in Charles County, is owned by Mirant Energy (formerly PEPCO). It has a total generating capacity of 1,411 MW, and utilizes a once-through cooling system with a capacity of 1M gpm. As with all other power plants in Maryland, Morgantown was the subject of intensive PPRP study and evaluation, as is summarized in Bongers et al. (1975). One CWIS issue of particular concern at Morgantown was the fact that organisms impinged on intake screens were transported in the screen wash trough to the cooling system discharge canal. The consequence of this fish handling system was that organisms that may have already been stressed due to impingement were then exposed to abrupt and significant temperature increases and thermal stress. Predictive assessments suggested that these combinations of stressors could result in survival rates considerably lower than were being documented at facilities such as Calvert Cliffs, where impinged organisms were discharged directly into the source water body. As a result of these concerns, PPRP requested that PEPCO investigate alternative fish return configurations and technologies. PEPCO's consultants identified and evaluated a number of different alternatives for reducing fish impingement losses, including a variety of diversion devices (e.g., louvers, revolving drum screens), behavioral barriers (e.g., bubble screens, lights, sound), fish collection devices (e.g., fish pumps), physical barriers (e.g., wedge-wire screens, barrier nets) and alteration of plant operations (Stone and Webster Engineering. 1981). This evaluation included an assessment of engineering feasibility and cost, as well as potential for reductions in impingement mortalities. In subsequent negotiations between the State and the plant owner, the diversion of screen wash from the discharge canal into the Potomac River main stem was determined to be the least cost means of achieving a substantial reduction in impingement mortality at this facility. That modification of CWIS was then considered to be BTA at this plant. In this instance, PPRP raised the issue with the plant owner, consulted on the work to be performed by the plant's contractor, and reviewed and utilized the study findings in making its NPDES CWIS recommendations to MDE.

Summer flounder	90
Northern searobin	50
Winter flounder	93
Northern pipefish	85
Hogchoker	99

Assessment of an alternative intake screening – While the mortality studies showed that consequences of impingement were not as great as implied by numbers of organisms impinged, impingement rates were high and remained a concern to PPRP. BGE undertook a number of investigations of alternative screening technologies to determine if such technologies could help reduce impingement. Among the screening technologies tested was Royce "Smooth-Tex" screens, finer mesh screens that offered the possibility of reducing entrainment of smaller species such as bay anchovy. These screens were installed in place of several of the existing traveling screens, but resulted in substantially higher impingement than existing screens at other intakes in the embayment. As a result, the technology was rejected for further study. This illustrates the iterative process that must often be followed in establishing whether a particular technology will be effective at a specific plant, and which of a number of technologies is the most effective means of achieving fish protection objectives. Maryland has addressed impingement and entrainment issues on a site-specific basis in this manner.

Assessment of factors contributing to impingement – In addition to evaluating alternative screen operations and alternative screening technologies, BGE and PPRP consulted on additional means of reducing impingement. The relatively high impingement rates during the early years of plant operation peaked in 1984 (Figure 5), when over 9 million fish were impinged (Ringger 2000). During a single major impingement episode, 46 thousand fish, primarily Atlantic menhaden, were impinged in a single hour at one unit in 1984. Episodes of this magnitude sometimes resulted in screen failure and plant shutdown, and it was thus of great economic value to BGE to reduce or eliminate the factors responsible for such episodes. A detailed evaluation of environmental conditions occurring during major impingement episodes revealed that they were associated with low dissolved oxygen conditions in the intake embayment. The curtain wall of the embayment, extending down to 8.5 m below the surface, was intended to have the plant draw cooler, bottom waters from the Bay. These deeper waters frequently exhibit low dissolved oxygen levels as well as low temperatures. When low dissolved oxygen events occurred, oxygen levels in the embayment dropped to lethal levels, and fish aggregated in the embayment were incapacitated and impinged in great numbers. A number of simple and inexpensive solutions were found to correct for these contributing factors. During periods when low dissolved oxygen conditions were most likely to occur, several curtain wall panels were removed, thus providing an oxygenated route for fish to move out of the embayment into open Bay waters. In addition, aerators were installed in the embayment to enhance surface oxygen levels. These simple measures resulted in a significant decline in impingement that has been maintained since they were implemented. Figure 5 illustrates the reduction in both numbers of fish impinged but also in mortality rates of those impinged fish. It should be noted that these reductions in impact were achieved with no change in screen technology or operation.

Conclusions

This brief overview provides several diverse examples of the process employed by Maryland in making power plant BTA determinations under Maryland's CWIS regulations. The major points I wish to convey include:

- Impingement and entrainment impacts can be significantly reduced by a wide variety of changes in intake structure operation, fish handling, external structure design, etc.; no single operational or technological change will have the same effects or benefits at all facilities
- Site-specific results of implementation of CWIS impact reduction measures cannot be accurately predicted, so site specific studies and evaluation are critical to successful, cost-effective reductions of CWIS impacts, and
- Cooperative efforts between regulators and permittees are the most timely and cost-effective way of ensuring that CWIS impacts are minimized

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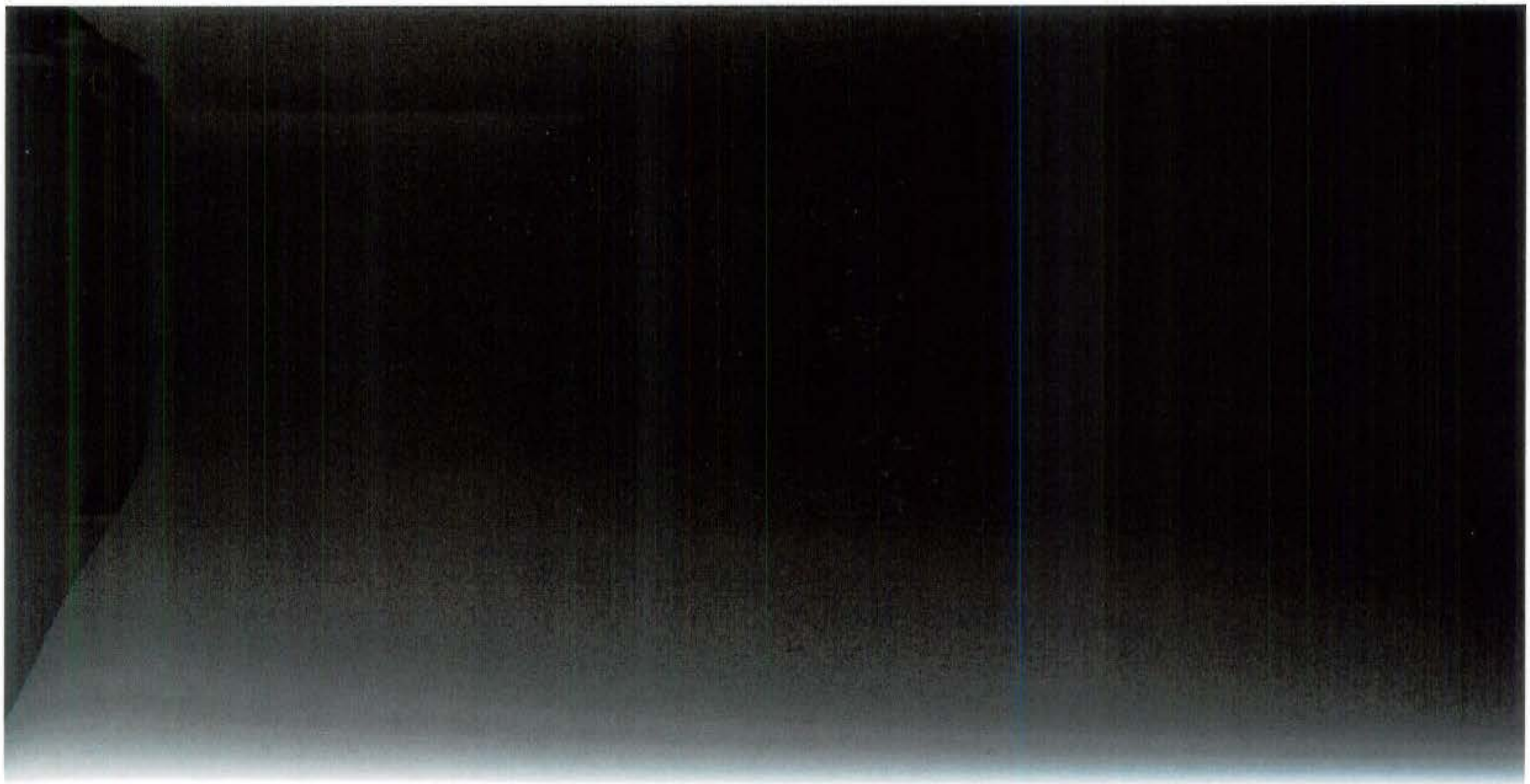
Abstract: Maryland is a state to which the U.S. Environmental Protection Agency (EPA) has delegated authority to administer the National Pollutant Discharge Elimination System (NPDES). In the late 1970's the state developed and implemented regulations for cooling water withdrawal and intakes in accordance with EPA guidance on implementation of Clean Water Act Section 316b provided at that time. The Code of Maryland Regulations (COMAR), 26.08.03.04-05, established procedures for determining adverse environmental impacts due to impingement and entrainment at cooling water intake structures (CWIS) relative to determination of best technology available (BTA) for minimizing these impacts. Maryland has applied these regulations to all power plants in Maryland that operate CWIS, including facilities located on both freshwater and estuarine waters. Over the past 30 years, the Power Plant Research Program (PPRP) of the Maryland Department of Natural Resources (MdDNR), has participated in or conducted studies of a wide range of technologies and processes including, for example, wedgewire screens, modifications to intake structures, Royce "Smooth Tex" intake screens, altered plant operations (e.g., screen rotation times), and installation of barrier nets. These evaluations resulted in a range of determinations, from deciding whether an existing CWIS already featured BTA to requiring installation of tested technologies at some facilities. Our 30 years of experience supports our contention that there is no single technology or suite of technologies that can be applied on a state-wide or national basis. However, we believe it is important to have a consistent national process for identifying BTA at the site-specific level.

Introduction

Maryland facilities that utilize cooling water intake structures (CWIS) are regulated by the Maryland Department of Environment (MDE), the state agency with authority and responsibility for National Pollutant Discharge Elimination System (NPDES) permitting, as delegated by the U.S. Environmental Protection Agency (EPA). Maryland's regulations relating to CWIS were developed based on EPA guidance on implementation of Clean Water Act Section 316b when that legislation was enacted in 1972, and are documented in the Code of Maryland Regulations (COMAR), 26.08.03.04-05. These regulations address all potential impact sources associated with withdrawal of cooling water, including entrainment and impingement. While MDE is responsible for regulation of CWIS, a sister agency, the Maryland Department of Natural Resources (MdDNR), provides the technical support employed to address CWIS impacts at power plants.



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September 10, 2015

U.S. Environmental Protection Agency– Region 1
5 Post Office Square, Suite 100
Mail Code OEP06-4
Boston, Massachusetts 02109-3912
Attn.: Remediation General Permit NOC Processing

Reference: **Notice of Change**
NPDES Remediation General Permit
10 CityPoint
494 and 500 Totten Pond Road
Waltham, Massachusetts
Permit #MAG910633

Dear Mr. Papadopoulos:

On behalf of James W. Flett Company, Inc. (Flett) and Commodore Builders, Lockwood Remediation Technologies, LLC (LRT) has prepared this Notice of Change (NOC) for the existing permit #MAG910633 in accordance with the Remediation General Permit (RGP) Appendix V Notice of Change, Suggested Forms and Instructions. The completed NOC form is attached to this letter.

Proposed Changed Conditions

This NOC has been prepared to document that construction dewatering activities have ceased on August 11, 2015. The anticipated restart of the construction dewatering activities will not be before December 9, 2015. At that time, start-up monitoring will continue when discharging has been initiated.

Please feel free to contact me at 774-450-7177 or at plockwood@lrt-llc.net if you have any questions or if you require additional information.

Sincerely,
Lockwood Remediation Technologies, LLC

Paul Lockwood

Paul Lockwood
President

Attachments: NOC Form

Please check all that apply:	Eligible changes for use of NOC:
☐	3. A change in treatment which:
☐	a) affects the design flow of the system but does not change the dilution factor to a value greater than five (5), where the discharge contains metals.
☐	b) adds or removes any major operable unit of the system
☐	4. The use of chemical treatment additives that will not add any pollutants which may cause a violation of receiving water standards or cause the overall effluent to violate effluent limitations. Attach the material safety data sheets (MSDS) and prior approval from the Director.
☐	5. Change of discharge location within the same receiving water as submitted in the NOI.
☒	6. Temporary cessation of discharge greater than 120 days. Describe (using additional sheets as needed): a) reasons for the interruption or cessation of discharge: Construction dewatering activities have temporarily been completed at this time. b) estimated time frame when the discharge will cease and be re-started: Ceased as of 8/11/15, anticipated re-start not before 12/9/2015 c) how "start-up" monitoring will resume when the discharge is re-started: Start-up monitoring will resume when the discharge is re-started
☐	7. Change in pH range in MA:
☐	8. Change to administrative information. Change in ownership? Y ○ N ○ If yes, what is date of ownership transfer (MM/DD/YYYY)? Is written agreement between the new and existing permittees containing a specific date for transfer of permit responsibility, coverage, and liability between them included? Y ○ N ○

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Broad-scale impacts of salmon farms on temperate macroalgal assemblages on rocky reefs

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ABSTRACT

Intensive fish culture in open sea pens delivers large amounts of nutrients to coastal environments. Relative to particulate waste impacts, the ecological impacts of dissolved wastes are poorly known despite their potential to substantially affect nutrient-assimilating components of surrounding ecosystems. Broad-scale enrichment effects of salmonid farms on Tasmanian reef communities were assessed by comparing macroalgal cover at four fixed distances from active fish farm leases across 44 sites. Macroalgal assemblages differed significantly between sites immediately adjacent (100 m) to fish farms and reference sites at 5 km distance, while sites at 400 m and 1 km exhibited intermediate characteristics. Epiphyte cover varied consistently with fish farm impacts in both sheltered and exposed locations. The green algae *Chaetomorpha* spp. predominated near fish farms at swell-exposed sites, whereas filamentous green algae showed elevated densities near sheltered farms. Cover of canopy-forming perennial algae appeared unaffected by fish farm impacts.

1. Introduction

Nutrient and sediment inputs from anthropogenic activities can cause changes to habitat structure and diversity in temperate reef ecosystems (Airoldi, 2003; Connell et al., 2008; Krause-Jensen et al., 2008; Worm et al., 1999b). These changes may affect delivery of ecosystem services to society, as well as marine conservation objectives for reef areas, which are disproportionately rich in species compared with other habitats. Whilst much attention has been focussed on terrestrial-derived pollution on reef (Arevalo et al., 2007; Connell et al., 2008; Costanzo et al., 2001; Giordani et al., 2009; Littler and Murray, 1975), eutrophication from marine fish farms may also pose a threat. Most previous monitoring and research programs relating to fish farm aquaculture have focused solely on changes to the soft sediments below and adjacent to farm lease areas, in-water nutrients levels, and phytoplankton populations (Edgar et al., 2010a).

Farmed salmon are commonly grown to maturity in net cages, situated in unpolluted sheltered temperate coastal waters. Salmon rely on nutrient-rich compound aquafeeds as an external food source (Tacon and Metian, 2008). Although improved feeding technology has provided a reduction in wasted feed input, Sanderson et al. (2008) suggested that about 70% of the nitrogen and 80% of the phosphorus input to a salmon farm is released to the environment as feed wastage, fish excretion, faeces production and respiration. The majority of these nutrients dissipate in dissolved form. Approximately 87% of nitrogen released from fish farms in the Huon Estuary, Tasmania, is estimated to be in dissolved form and 13% as particulate matter (HEST, 2000b, a). The impact of particulate fish farm waste on sediment communities is variable, according to interactions between depth, current speed, current direction, sediment type, and latitude (Kalantzi and Karakassis, 2006). Commonly impacts are found to be relatively localised (Borja et al., 2009; Grego et al., 2009; Ye, 1991), with meta-analyses reporting benthic community change extending 40–70 m on average (Giles, 2008), although instances of impacts to 145 m have also been recorded (Hamoutene et al., 2015). The extent of impact of dissolved wastes is poorly known, but may extend further (HEST, 2000a).

The effects of fish farm derived nutrients on the diversity and composition of macroalgal-dominated reef communities are likely to be similar to those already observed in eutrophic systems affected by terrestrial derived organic pollution, such as sewage and runoff from fertilised landscapes. A well-documented consequence of excessive nutrients in coastal reef environments is the over-abundant growth of certain types of productive, fast growing macroalgae (Bokn et al., 2003b; Krause-Jensen et al., 2008;

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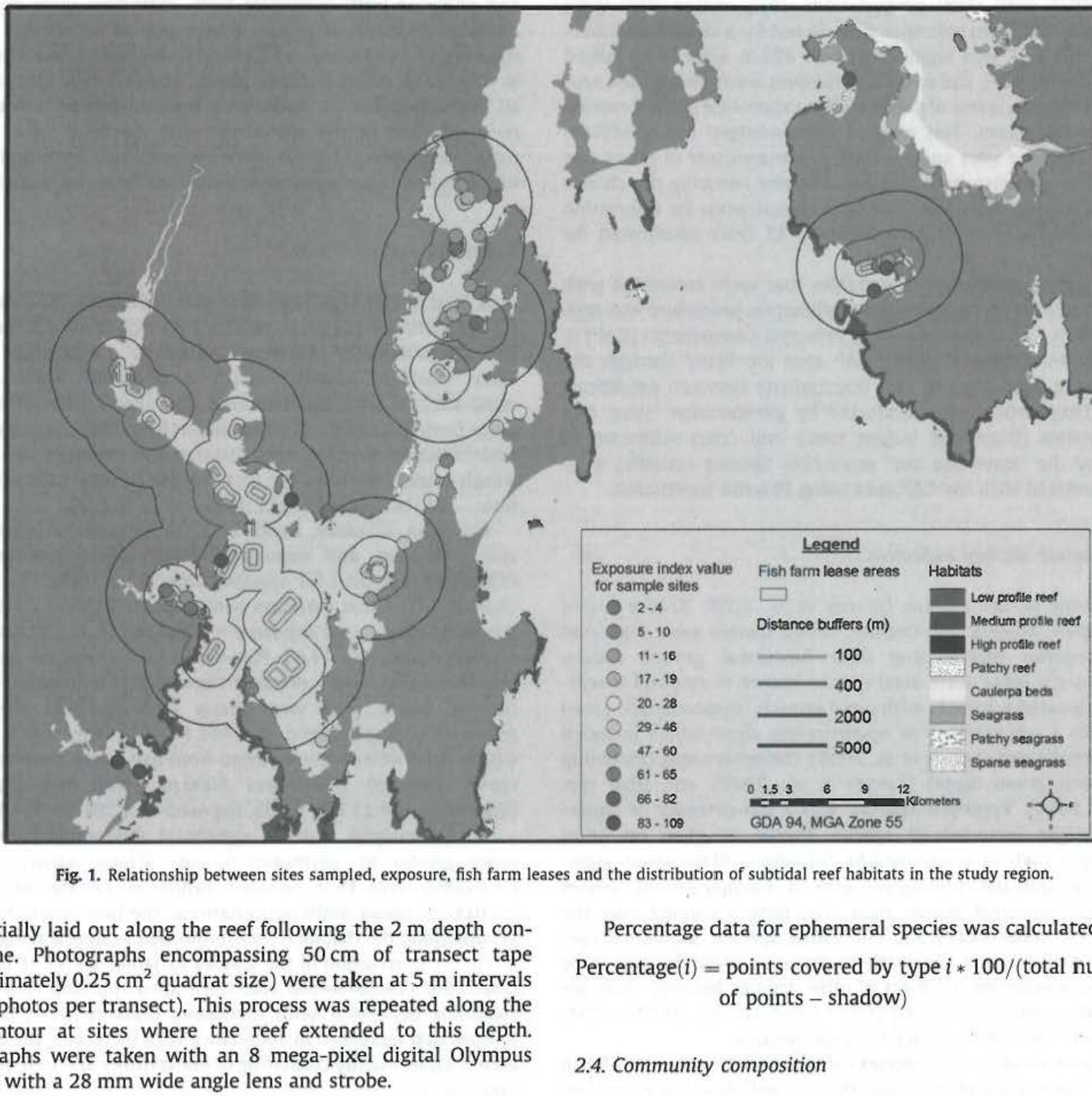

Fig. 1. Relationship between sites sampled, exposure, fish farm leases and the distribution of subtidal reef habitats in the study region.

was initially laid out along the reef following the 2 m depth contour line. Photographs encompassing 50 cm of transect tape (approximately 0.25 cm^2 quadrat size) were taken at 5 m intervals ($n = 10$ photos per transect). This process was repeated along the 5 m contour at sites where the reef extended to this depth. Photographs were taken with an 8 mega-pixel digital Olympus camera, with a 28 mm wide angle lens and strobe.

2.3. Data processing and analysis

Photos were cropped and adjusted for brightness and contrast before being imported into CPCe (Coral Point Count with excel extension) for analysis. A point count method was used, where points are overlayed over an image and the species beneath each point visually identified and recorded in a database (Kohler and Gill, 2006). For each image, a grid of 56 points was overlayed with an image border of 100 pixels. Points where the underlying algae could not be identified to species were lumped into a higher category, such as '*Sargassum* spp.', or 'foliose red algae'.

Results for each transect were exported, and percentage cover (per transect) calculated for each cover type. Adjustments were made so that obstruction by ephemeral epiphytic algae did not bias the coverage estimate for the more permanent underlying algal community. Percentage cover for the underlying community was calculated as:

$$\text{Percentage}(i) = \text{points covered by type } i * 100/(\text{total number of points} - \text{the points attributed to ephemeral coverage} - \text{shadow})$$

Percentage data for ephemeral species was calculated as:

$$\text{Percentage}(i) = \text{points covered by type } i * 100/(\text{total number of points} - \text{shadow})$$

2.4. Community composition

The percentage cover data of macroalgae and sessile invertebrates on each transect sample were square root transformed for multivariate procedures to reduce the influence of dominant species. We used Bray--Curtis as the distance measure. Both non-metric multidimensional scaling (MDS) and principal coordinate analysis (PCO) ordinations were examined for 2D and 3D solutions.

To test the null hypothesis that community composition was not significantly different between samples with different environmental variables, a PERMANOVA test was conducted (Primer-E 2008). In this case, the model included the fixed categorical factors 'depth', 'distance' and an exposure index (oceanic swell-exposed versus non swell-exposed), and all interaction terms. Calculation of the Pseudo-F ratio and P value ($\alpha = 0.05$) was based on 9999 permutations of residuals under a reduced model. The components of variation attributed to each factor were calculated (Anderson et al., 2008). Negative estimates of components of variation were consecutively pooled, starting with the term with the smallest mean-square value, as suggested by Anderson et al. (2008).

A restricted set of *a posteriori* pair-wise tests was also conducted if the term 'distance' or its interaction with another term was found to be significant. This was also done using

Table 1
Table of results, and estimates of components of variation for PERMANOVA with square root density data and Bray–Curtis distance matrix.

Source	Degrees of freedom	Sum of squares	Mean Square	Pseudo-F ratio	*P* value (by permutation)	Components of variation
Exposure	1	41,000	4100	25.700	0.001	1210
Depth	1	4310	4310	2.700	0.001	80
Distance	3	11,500	3850	2.412	0.001	135
Exposure × depth	1	3930	3930	2.464	0.004	138
Exposure × distance	3	11,500	3840	2.406	0.001	268
Pooled residuals*	63	100,000	1600			1595
Total	72	172,000				

* SS and degrees of freedom for terms *depth* × *distance* and *exposure* × *depth* × *distance* were pooled with the residuals as they had negative estimates of components of variation.

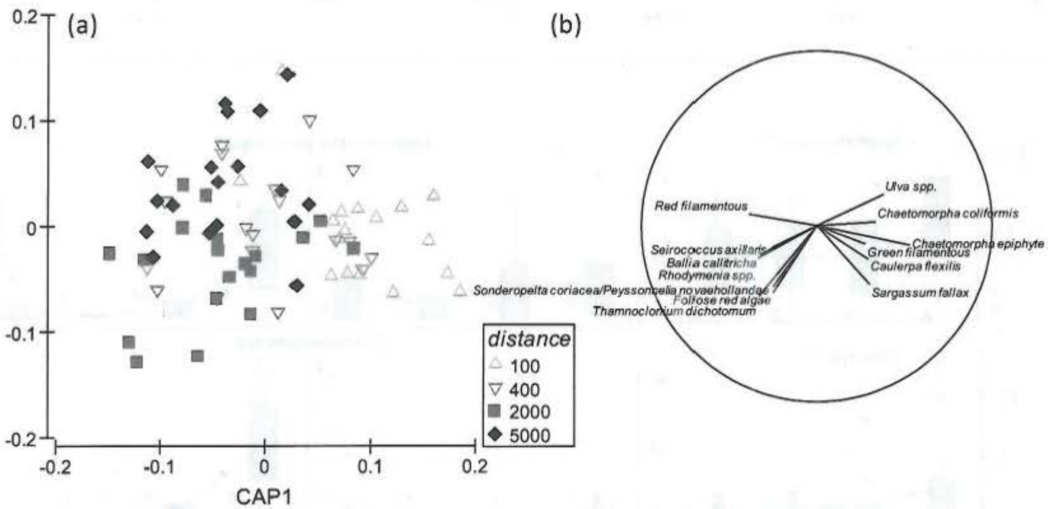

Fig. 3. (a) CAP ordination from a discriminant analysis by distance, using a Bray--Curtis matrix of square root species abundance data. (b) Fitted vectors of species variables correlated with CAP axis 1 (Pearsons correlation coefficient >0.25).

The 'leave one out' allocation procedure showed that sites 100 m from fish farms shared the most consistent macroalgal community composition, achieving correct classification for 76.5% of the samples in that group (Table 2). Sites from other distances, particularly 400 m sites, were much more variable. Misclassification of 400 m sites into the 100 m category occurred in 5 cases. Misclassification of 400 m sites into 2000 m sites and 5000 m sites occurred 5 and 6 times respectively. Sites 2000 m and 5000 m from fish farms had low misclassification rates for the 100 m group (Table 2).

All of the groups identified *a priori* as potential nutrient indicators had high frequencies of occurrence amongst the transect samples. Canopy brown algae dominated most sites, averaging 46% cover. Filamentous brown algae and algal turf were also widespread and abundant on many transects. The high cover of filamentous brown algae meant that it was the dominant component of the epiphytes.

Most groups responded significantly to exposure, or an interaction between exposure and distance (Table 3). There were several trends in cover over the four distance categories (Fig. 4). The cover of epiphytic algae and *Ulva* spp. were significantly different between distance categories (Table 3). Epiphytic cover was significantly higher for 100 m sites than for 400 m, 2000 m, and 5000 m sites (Fig. 4). *Ulva* spp. was more dominant at the 100 m sites than 5000 m sites. The interaction factor distance × exposure was significant for *Chaetomorpha* spp., filamentous algae and opportunistic green algae. *Chaetomorpha* spp. were in greatest cover at swell exposed sites 100 m from fish farms, covering an average of 21.4% of each transect. This group of sites was significantly different from all other sites. Filamentous algae were much more abundant at sheltered sites than exposed sites. At sheltered sites, the abundance of these algae was significantly higher at 100 m sites than 2000 m and 5000 m reference sites. However, no significant distance effect was seen at exposed sites. Filamentous green algae showed a pattern of decreasing cover with increasing distance from fish farms, in total and at sheltered sites. Opportunistic greens were dominated by filamentous green algae at sheltered sites, and *Chaetomorpha* spp. at swell exposed sites. At sheltered sites, the cover of opportunistic greens decreased with increasing distance from fish farms.

Table 2
Leave-one-out allocation of observations to groups, for the choice of $m = 9$.

Original group	Classified					
	100	400	2000	5000	Total	%correct
100	13	1	1	2	17	76.5
400	5	4	4	6	19	21.1
2000	2	4	9	4	19	47.4
5000	0	6	4	8	18	44.4

4. Discussion

Given the consistency of biological response amongst interspersed sites distributed regionally, the most plausible explanation for observed variation in algal community composition with distance from fish farms is impact associated with release of nutrients. The nature of these impacts varied between wave-exposed and sheltered locations in a manner consistent with expectations from previous studies (Barrett et al., 2001; Burrows et al., 2008;

phytoplankton blooms, with flow on effects to benthic macroalgal systems (Krause-Jensen et al., 2007a; Krause-Jensen et al., 2007b). The consistent effect at the two depths investigated in our study indicates that nutrients probably dispersed throughout the depth range sampled on the majority of farm-affected reefs in the area.

As in other studies on nutrient enrichment and macroalgal composition (Arevalo et al., 2007; Juanes et al., 2008; Russell et al., 2005), fish farms impacts were characterised by increases in epiphyte cover. The high cover of opportunistic species suggests that, for the seasonal period sampled, algal growth was nutrient-limited. Thus, the ecosystem was unable to counteract increased growth of opportunistic algae through grazing or physical disturbance. Algal turf did not exhibit a notable increase towards fish farms. However, the ability to detect turf may have been compromised by the use of photo-quadrats, as this algal functional group is associated with the rock substratum and is generally obscured by foliose algae. Similarly, no obvious trend in red filamentous algae was evident, and this group often grows under other filamentous or foliose algae iin reduced light conditions, so may have been obstructed in photos.

Secondary impacts resulting from overgrowth of epiphytic algae were unclear. Canopy algae did not detectably decline near fish farms, as has been reported for other cases of eutrophication (Cebrian et al., 2014). Three potential explanations for this result are that macroalgal communities in the region perhaps display some resilience to extreme effects of nutrient enrichment, nutrient levels were insufficient to generate such responses, or insufficient time had elapsed since establishment of farms for full effects to manifest.

Previous studies on fish farm impacts in Tasmania have largely focussed on benthic soft sediment habitats (Crawford et al., 2002; Edgar et al., 2005; Macleod et al., 2002; Macleod et al., 2004), with subtle or intermediate impacts detected at regulatory compliance sites located 35 m from lease boundaries (Edgar et al., 2010b; Edgar et al., 2005). More recent reports emphasize the need for broad-scale monitoring (Ross and Macleod, 2013).This study indicated that fish farms had a significant effect on benthic reef communities at greater distances than regulatory compliance sites, and combined with the distribution of fish farms, impacts regional in nature are also of concern. Fish farms affected reef benthic communities at both sheltered and exposed sites to at least 100 m from fish farms, at which point macroalgal communities differed significantly from reference sites. Although sites at 400 m distance were not significantly different to reference sites when assessed collectively, effects extended this distance in some areas but not others, generating wide confidence intervals associated with the overall mean. This was indicated by the leave-one-out procedure in CAP, which revealed 5 of the 400 m sites showed characteristics akin to 100 m sites, compared to none of the 5000 m reference sites and two 2000 m sites.

Our results thus suggest nutrient enrichment from fish farms affects subtidal reef communities to a variable distance, and at scales of hundreds of metres, but rarely kilometres. A caveat associated with this conclusion is the assumption that impacts did not extend throughout the whole farming region, in which case reference sites at 5-km distance from farms would not provide appropriate controls for assessing impacts. Regardless, previous studies on the dispersal of nutrients from fish farms have concluded that nutrient enrichment occurred within a range of hundreds of metres. Algal growth in bioassays was significantly elevated to 150 m from fish farms in the Mediterranean Sea (Dalsgaard and Krause-Jensen, 2006), while in Scottish waters ammonium levels at 4 m depth were elevated for extended periods of the day at distances exceeding 200 m (Sanderson et al. 2008). A region-wide study by Husa et al. (2014) assessed macroalgal communites that were more than 1 km from salmonid farms, and found them to be of 'high' or 'good' ecological status under the indices of the European Water Framework Directive.

Distance from fish farm provides a highly simplified metric of the influence of any fish farm due to complexities associated with output and dispersal of nutrients, and susceptibility of the marine environment to nutrient enrichment. Current direction and strength, in particular, greatly affect the footprint of nutrients and particulate wastes dispersing from fish farms (Ali et al., 2011; Giles, 2008; Venayagamoorthy et al., 2011). Nutrient enhancement generally extends much further in the direction of prevailing currents, and in some cases may not be detectable in the opposite direction (Sanderson et al. 2008). However, sites in the present study were identified purely on the basis of distance to nearest fish farm, reef location, a wide spatial distribution of sites, wave exposure, and absence of other pollution types. Including prevailing current directions from each fish farm may have improved models and reduced statistical noise in the effects seen at different distances from farms, if current data were available at appropriate temporal and spatial scales, and adequately captured time integrated patterns. These considerations, as well as fish pen distribution and stocking levels, feeding regimes, and characteristics of the reef habitat studied, such as the abundance of grazers, will be important aspects of future and finer-scale studies. Nevertheless, considering the high density of fish farms, the lack of previous monitoring of aquaculture related reef impacts in the broader area, and the seasonal and inter-annual variability in the hydrodynamics of the study area (Harris et al., 1987), it was considered prudent to focus on overall dominant patterns on a regional scale. Regional scale models can encompass variability in tidal currents and the cumulative impacts of multiple fish farms (Symonds, 2011).

Regardless of this variability, impacts of farm-released nutrients were arguably easier to detect using macroalgae than by monitoring the nutrients themselves (Dalsgaard and Krause-Jensen, 2006). Nutrient concentrations vary greatly through the day, requiring repeated sampling, whilst growth in macroalgae is a cumulative effect of locally-elevated nutrients over a longer time period (Munda, 1993). Nitrogen isotopes in macroalgae have also been used to detect fish farm effluent, however values must be referenced specifically for each region and species studied (Carballeira et al., 2013). Macroalgal composition thus represents an important tool for comprehensive monitoring programs in fish farming regions containing reef habitat.

Our results provide a snapshot of algal communities on reefs at a relatively early stage of regional fish farm development, given that the majority of Australian salmonid production occurs within the region studied, with annual growth of up to 20% in Australian production varying in the five years prior to 2011, and a 50% expansion projected to 2016 (Curtotti et al., 2011). Whilst no major decline in algal canopy cover was detected near farms in our study, ongoing nutrient enrichment from fish farms remains a potential threat to macroalgal community structure and reef diversity through the long-term. The apparent barren-state of a reef 100 m from a fish farm at Port Esperance, which had low canopy cover, a high density of grazers, and a high opportunistic green algal cover, was notable in this regard. This situation may indicate complex relationships involving grazers, nutrients, sedimentation and canopy loss; however, additional research is needed to assess this.

A comprehensive understanding of impacts of fish farm nutrients on reef communities requires knowledge of seasonal relationships between grazers, foliose algal canopy cover, and growth of filamentous and other opportunistic algae. Experimental manipulations of grazers, nutrients, propagule banks, and/or disturbance would usefully add to *in situ* observational studies in providing such information (Bokn et al., 2003a; Kraufvelin, 2007; Worm et al., 1999a; Worm et al., 2002), thereby allowing effects and

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