The New Zealand King Salmon Company Limited: Assessment of Environmental Effects - Submerged Artificial Lighting
The New Zealand King Salmon Company Limited: Assessment of Environmental Effects - Submerged Artificial Lighting

Chris Cornelisen

Prepared for
The New Zealand King Salmon Company Ltd

Cawthron Institute
98 Halifax Street East, Private Bag 2
Nelson, New Zealand
Ph. +64 3 548 2319
Fax. + 64 3 546 9464
www.cawthron.org.nz

Reviewed by:  David Taylor
Approved for release by: Rowan Strickland

Issue Date: 22 September 2011
Recommended citation:
EXECUTIVE SUMMARY

The New Zealand King Salmon Company Ltd. is seeking a Plan Change and resource consent which would provide for the installation of submerged artificial lighting on proposed salmon farms in the Marlborough Sounds. The benefits of submerged artificial lighting to the finfish aquaculture industry are significant; by virtually removing changes in light as an environmental variable, farms can greatly increase production and reduce the risk of early maturation prior to harvest. Placing submerged lighting at depth (versus near the surface) during night-time hours also assists in evenly distributing the fish in cage structures and reducing fish densities near the surface.

Artificial lighting directly affects the physical characteristics of the water column and as a result has the potential to have an effect on a number of biological processes both within and adjacent to cage structures. This report provides an assessment of the environmental effects likely to arise from the use of submerged artificial lighting on salmon farms in the Marlborough Sounds. The assessment is based on a review of the literature and observations made during a site visit to the Clay Point salmon farm where artificial lighting is currently used. The site visit included field measurements of underwater light levels both within and adjacent to illuminated farm cages. In addition, vertical plankton tows were collected in order to assess the potential effects of lighting on the zooplankton abundance and community composition.

Based on the assessment, the effects on the surrounding marine environment are likely to be highly localised, both in terms of the physical effects on the underwater light environment and subsequent biological and ecological (e.g. food web) effects. The ‘footprint’ of submerged artificial lights are mainly confined to the cage structures and to mid-water depths; hence organisms along the bottom or further than about 10 m from cage structures are unlikely to be affected. The most likely effect of submerged artificial lighting associated with the proposed farms will be the enhanced attraction and aggregation of some organisms, such as baitfish, during night hours. Fish that enter the cage structures could become trapped once they become too large to exit the cages through the mesh and could be predated upon by the salmon. The level of predation on baitfish by salmon will depend on the life stage of the salmon within the cages and will be limited due to the fact that the salmon are fed an artificial diet. According to farm staff, baitfish trapped within the cage structures are also released during harvest.

Based on the physical characteristics of the sites to be developed, the scale of the farms compared to the wider Sounds, and the small spatial footprint of the artificial lights, the effects of the submerged artificial lighting on the surrounding marine environment are likely to be no more than minor. The total volume of the two Sounds combined is roughly 9,400 times the size of the total volume that will be occupied by the farms (based on a total area of 11 hectares (110,000 m²) of surface area for eight farms and a cage depth of 20 m). Hence, while the effects of artificial lighting may be measureable at some level within the cage structures, the effects in terms of the much larger marine ecosystem of the Marlborough Sounds will be very small and unlikely measureable.

Placement of the farms in areas of deep water and high currents will assist in mitigating attraction and aggregation of organisms within cage structures. To further minimise effects, efforts should be made
to ensure that only the amount of lighting required for beneficial outcomes is used (i.e. unnecessary over-powering of lights should be avoided). This assessment included observations made during one site visit and it is likely that the effects of artificial lighting vary according to water column conditions. To further confirm that effects are of a small magnitude, we would recommend a follow-up site survey at a farm where lights are fully operational. An ‘observer’ approach to monitoring effects of artificial lighting under varying conditions is also recommended. Observations by farm staff could include noted changes in night-time feeding activity by fish, seabirds and marine mammals in and around the illuminated cages. In addition, inspection of gut contents during routine inspections of fish for disease and condition would assist in determining whether the salmons’ diet is subsidised by wild prey.
TABLE OF CONTENTS

EXECUTIVE SUMMARY......................................................................................................... III

1. THE USE OF ARTIFICIAL LIGHTING IN SALMON FARMING ........................................... 1

2. DESCRIPTION OF EXISTING ENVIRONMENT/ISSUES ................................................. 2
   2.1. Existing use of artificial lighting in the Marlborough Sounds................................. 2
   2.2. The physical effects of artificial lighting................................................................. 3
   2.3. Potential environmental effects associated with the use of artificial lighting ............ 4

3. ASSESSMENT OF ECOLOGICAL EFFECTS ..................................................................... 6
   3.1. Attraction of phototaxic organisms ........................................................................... 6
   3.2. Vertical migration and benthic settlement of planktonic organisms ......................... 8
   3.3. Aggregation and visibility of prey and enhanced predation ..................................... 9
   3.4. Vertical distribution of salmon and risk of parasitism ............................................... 10
   3.5. Attraction of birds ................................................................................................... 10

4. EVALUATION OF EFFECTS AND THEIR SIGNIFICANCE ........................................... 12

5. CONCLUSIONS AND RECOMMENDED OPTIONS FOR MITIGATION AND MONITORING .................................................................................................................. 14

6. REFERENCES................................................................................................................. 15

LIST OF FIGURES

Figure 1. Location of the five King Salmon farm sites currently in operation in the Marlborough Sounds. ............................................................... 2
Figure 2. The two cages at Clay Point salmon farm that are currently illuminated at night using submerged artificial lights............................................ 3
Figure 3. Photographs of the illuminated cages taken at 2330 from the second floor of the support building at the Clay Point salmon farm. ........................... 4
Figure 4. Mean (±1 SE) number of individuals per 1000 litres for the six most abundant zooplankton taxa in plankton tows (n=3) collected within and outside an illuminated cage (left side of graphs) and within and outside a ‘dark’ cage (right side of graphs). .............................................. 7
Figure 5. Total number of mysid shrimp in individual plankton tows according to time of collection. ............................................................................. 8

LIST OF TABLES

Table 1. Potential issues and subsequent environmental effects of submerged artificial lighting in the marine environment .......................... 5
Table 2. Summary of key issues and the magnitude of ecological effects likely to arise from artificial lighting .......................... 13
1. THE USE OF ARTIFICIAL LIGHTING IN SALMON FARMING

The use of submerged artificial lighting during night-time hours is common practice in salmon farming overseas and is gaining increased interest in application in New Zealand. It is well documented that artificial lighting inhibits the rate of maturation (grilising) in Atlantic salmon that arises as a function of seasonal changes in the day/night cycle, or ‘photoperiod’ (e.g. Porter et al. 1999). More recent research in New Zealand indicates that continuous artificial lighting for farming of King Salmon results in similar benefits with regard to inhibiting maturation (Unwin et al. 2005). The benefits of artificial lighting to the aquaculture industry are significant; by virtually removing changes in light as an environmental variable, farms can greatly increase production and reduce the risk of early maturation prior to harvest. Placing submerged lighting at depth (versus near the surface) during night-time hours also assists in evenly distributing the fish in cage structures and reducing fish densities near the surface (Juell et al. 2003).

Artificial lighting directly affects the physical characteristics of the water column and as a result has the potential to have an effect on a number of biological processes surrounding the salmon farms. The following sections summarise the potential effects based on a review of the literature and observations made during a site visit to the Clay Point Salmon Farm where artificial lighting is currently used (Cornelisen & Quarterman 2010).
2. DESCRIPTION OF EXISTING ENVIRONMENT/ISSUES

2.1. Existing use of artificial lighting in the Marlborough Sounds

The New Zealand King Salmon Company Limited (NZ King Salmon) currently farms King Salmon (*Oncorhynchus tshawytscha*) in sea cages at five sites in the Marlborough Sounds (Figure 1). Artificial lights are in operation in two 30 x 30 m cages at the Clay Point site in Tory Channel. As part of their operations, NZ King Salmon recently gained resource consent to install submerged artificial lighting in cages at the Te Pangu site, which lies to the south of the Clay Point site (Figure 1, see Cornelisen & Quarterman 2010). Other than for the purpose of salmon farming at these locations, there is no known use of submerged artificial lighting in the Marlborough Sounds.

![Figure 1. Location of the five NZ King Salmon farm sites currently in operation in the Marlborough Sounds.](image)

Based on current practice, artificial lighting within a 30 m x 30 m cage structure is produced using an array of 1000 watt halogen bulbs that are suspended either in a circular pattern or along two parallel lines (Figure 2). Optimal light configurations are currently being determined; the most likely configuration consists of a ring of eight lights that lie along a circle 16 m in diameter with the lights alternated at depths of 5 and 10 m.
Figure 2. The two cages at Clay Point salmon farm that are currently illuminated at night using submerged artificial lights. Lights are alternately suspended at 5 and 10 m beneath the white buoys.

2.2. The physical effects of artificial lighting

In order to assess the environmental effects of artificial lighting on the marine environment, the physical effects of the lights need to be described first. This includes determining the spatial ‘footprint’ of the artificial lights (i.e. the depths that the light penetrates to and the size of the area affected within and around the cage structures). As part of the consent application to install artificial lights at the NZ King Salmon Te Pangu farm, a site visit to the Clay Point farm was carried out in order to obtain field measurements of underwater light levels and attenuation through the water column both within and adjacent to illuminated farm cages (Cornelisen & Quaterman 2010). While this dataset is limited to the conditions during one site visit, the measurements and observations provide insight into the nature and magnitude of physical effects that arise from artificial lighting within salmon farm cages in the Marlborough Sounds.

Based on personal observations from above the water, the illuminated ‘visual’ footprint of each light was circular in appearance, with a diameter of influence of about 10 to 12 m (Figure 3). The light appeared to be mainly confined to the area enclosed by the cages. In an area of one of the cages where a light was less than 5 m from the cage edge, low levels of light were observed beyond the cage structures to a distance of about 3 to 5 m. Based on observations by farm workers, the extent to which light extends beyond the cage structures varies over time, and when the water is visibly clear the light has been observed in the order of 5 to 10 m beyond the cage structures.
Based on measures of downwelling irradiation, the depths most influenced by the artificial lights were between 5 and 15 m depth and the levels of light greatly diminish (to almost immeasurable levels) along the inside edges of the cage. These results indicated that the footprint of the lights is relatively small and restricted to mid-water depths and primarily within the cage structures (Cornelisen & Quarterman 2010). Light measurements were also recorded over a 10-day period at the surface and 7 and 12 m depths within the illuminated cage. Patterns of irradiation associated with changes in sunlight and light attenuation through the water column were apparent, however, the light sensors were unable to detect light emitted from the artificial light array during night hours. This was likely due to the fact that the light is primarily directed outward and within a narrow visible band.

### 2.3. Potential environmental effects associated with the use of artificial lighting

Due to the small spatial area and volume of the farm structures in comparison to the wider Sounds and the great distances between farm sites, the cumulative effects of submerged lighting from multiple farms are highly unlikely. The issues that artificial lighting imposes are in relation to organisms and processes in the water column surrounding the area impacted by the lights. Based on observations of the rapid attenuation of light underwater and the small spatial footprint of the area illuminated by the lights, the environmental effects of artificial lighting in salmon cages on the surrounding marine environment will be localised.

Light pollution due to artificial lighting has received considerable attention in terrestrial systems; widely cited examples of impacts on land include effects of tall lighting structures on mortality of migratory birds and the disorientation of sea turtle hatchlings by lights associated with coastal developments (Longcore & Rich 2004). The effects of artificial lighting in the marine environment are less known, particularly with regard to salmon farms. Possible environmental effects of artificial lighting associated with coastal and ocean structures are summarised in Table 1 and assessed fully in Section 4 below.
Table 1. Issues and possible environmental effects of submerged artificial lighting in the marine environment

<table>
<thead>
<tr>
<th>Issue</th>
<th>Possible Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attraction of phototaxic organisms</td>
<td>Organisms such as zooplankton and larval fish may be attracted to the lights and accumulate near and/or within the farm structures.</td>
</tr>
<tr>
<td>Vertical migration and benthic settlement</td>
<td>Vertical migration in the water column by some phytoplankton and zooplankton species may be influenced by light. There may also be enhanced settlement of organisms attracted by the light onto the seabed near farm structures.</td>
</tr>
<tr>
<td>of planktonic organisms</td>
<td></td>
</tr>
<tr>
<td>Aggregation and visibility of prey and</td>
<td>Baitfish may be attracted to the lights and aggregate near and/or within illuminated cages. Visibility of prey during night-time hours will increase. Increased aggregation and visibility of prey could in turn increase rates of predation by the farmed salmon as well as fish and marine mammals (e.g. seals) outside the cages.</td>
</tr>
<tr>
<td>enhanced predation</td>
<td></td>
</tr>
<tr>
<td>Vertical distribution of salmon and</td>
<td>Submerged artificial lighting influences the depth distribution of salmon. Increased densities of salmon at a given depth can increase risk of parasitism by some species of zooplankton (e.g. sea lice).</td>
</tr>
<tr>
<td>risk of parasitism</td>
<td></td>
</tr>
<tr>
<td>Attraction of birds</td>
<td>Birds flying overhead may be attracted to the lights and as a result could collide or become entangled within the farm structures.</td>
</tr>
</tbody>
</table>
3. **ASSESSMENT OF ECOLOGICAL EFFECTS**

3.1. **Attraction of phototaxic organisms**

Artificial lighting is an effective means of attracting small marine organisms, such as larval fish and zooplankton; light emitting traps are routinely used to collect larval fish and zooplankton samples in aquatic environments (e.g. Hickford & Schiel 1999; Lindquist *et al.* 2005). Surface and submerged artificial lights are also used for both recreational and commercial fishing due to the attraction of baitfish and in turn, predators to the illuminated water. For example, the majority of the world’s squid fishery utilises artificial lighting and a single vessel can utilise up to 150 lamps (300 Kilowatts) while fishing (Rodhouse *et al.* 2001).

Based on these observations, illuminated salmon cages have the potential to attract phototaxic organisms to the edge of the cage structures, and within the cage for those organisms small enough to fit through the mesh. There are very few published studies on the effects of artificial lighting in salmon farms on larval fish and zooplankton. A study by McConnell *et al.* (2010) found that the same lights used in salmon farming attracted only marginally (and non-significantly) larger numbers of zooplankton than non-illuminated cages.

These observations are consistent with those made during a site visit to the Clay Point Salmon Farm (Cornelsen & Quaterman 2010). During the site visit, vertical plankton tows were conducted to evaluate differences in zooplankton species composition and abundance between cages with and without artificial lighting. In addition, tows were conducted outside the cages to assess the effects of the cages regardless of artificial lighting. For the two most abundant taxa groups (copepods and comb jellies), there were significantly more organisms observed in samples collected outside the cages than within the cages (Figure 4); however, there was no significant difference between illuminated and dark sampling locations and no significant interaction between the two variables (based on a two-factor analysis of variance). These results suggest that the cage structures, independent of lighting, affect abundance of some organisms. For instance, hydrodynamic processes associated with the high currents at the site may limit entrainment of small-sized zooplankton into the cages due to turbulence and boundary layer effects along the surface of the predator exclusion and cage nets. The lower organism abundances within cages may also be due to feeding on zooplankton by high numbers of baitfish within the cages. With regard to artificial lighting, the number of some planktonic organisms may also be “artificially reduced” due to higher rates of predation within illuminated cages than dark cages.

Mysid shrimp were the largest organisms observed in the net samples (~5 to 10 mm in length) and were more abundant in the illuminated cage than at the other sample locations (Figure 4). However, a plot of their abundance according to time of sample collection (Figure 5), suggests processes other than light attraction were driving the differences observed between sampling locations. Factors could have included time-dependent emergence into the water column or perhaps movement of dense patches of organisms into and out of the farm with the tide. In
summary, the findings indicate that the artificial lighting has little effect on the abundance of zooplankton in and around cage structures.

**Figure 4.** Mean (±1 SE) number of individuals per 1000 litres for the six most abundant zooplankton taxa in plankton tows (n=3) collected within and outside an illuminated cage (left side of graphs) and within and outside a ‘dark’ cage (right side of graphs).
According to results from McConnell et al. (2010), artificial lights can result in a significantly higher abundance of larval fish in the water column. It is emphasised, however, that the study by McConnell et al. (2010) was conducted outside of actual salmon cages, and that the cages themselves can have an effect on organism abundances (see Figure 4 for example). During the site visit to Clay Point, no larval fish were collected in the tows, suggesting that they were either in very low abundance or that the method was not an effective sampling method for catching larval fish. The presence of larval fish in the water column can be highly episodic and often seasonal for some species.

While some fish larvae are known to be attracted to lights (Lindquist et al. 2005) it is unlikely they would be able to sustain their position within the cages due to the strong currents at all but one of the proposed farm sites (see Water Column Report by Gillespie et al. 2011; Lindquist & Shaw 2004). Experiments on the effectiveness of light traps indicate that current flow over 30 cm s\(^{-1}\) leads to an inability to trap a range of larval fish species using artificial lights (Lindquist & Shaw 2004). Many of the existing salmon farms in the Marlborough Sounds and the proposed farms are situated in areas where currents frequently exceed 30 cm s\(^{-1}\) (Dunmore et al. 2010; Forrest et al. 2010); hence larval fish will unlikely be able to remain in cage structures for durations longer than a few hours during slack tide. Some larvae, such as those of blue cod, are not pelagic and settle onto rocky bottoms (Robertson 1973; Carbines et al. 2004).

### 3.2. Vertical migration and benthic settlement of planktonic organisms

Submerged artificial lighting has the potential to influence vertical migration of zooplankton within the area illuminated by the lights. In lakes, diel migration of zooplankton (movement between deep and shallow waters) is thought to be largely a function of predation (Nesbitt et al. 2005).
al. 1996) and it has been further demonstrated that the relative influence of predation is lessened at high latitudes where the period of darkness is minimal during summer months (Hansson et al. 2007); for example, copepods typically migrate from the bottom into the water column at night under the cover of darkness. Some variability in the degree of migration in zooplankton occurs as a function of moon phase, with greater numbers of zooplankton observed in the water column during new moons versus full moon evenings when they would be more visible to predators such as fish. Studies have shown variability in the influence of light on vertical migration; for example, the timing of migration into the water column by some species of copepods and mysid shrimps does not correlate with levels of moonlight whereas moonlight can inhibit migration by amphipods and isopods (Alldredge & King 1980).

In the case of salmon farms, the extent to which lights influence vertical migration will be dependent on the depth to which the light penetrates relative to the bottom, the communities living beneath the light structures, and the level of water column currents, which presumably would also influence the spatial distribution of zooplankton. The effects of salmon farms in the Marlborough Sounds on the benthos are well documented (Keeley et al. 2010). Organic enrichment within the footprint of the farms results in benthic communities that are low in diversity and dominated by polychaetes. Hence, any influence on vertical migration of zooplankton within the water column would be on those organisms that have already migrated off the bottom elsewhere and have been carried into the vicinity of the farms. Based on the very small volume of the farms in comparison to the wider Sounds, the subsequent effects of artificial lighting on benthic settlement of planktonic organisms is expected to be very small.

3.3. Aggregation and visibility of prey and enhanced predation

Some fish species are known to aggregate around submerged artificial lighting (McConnell et al. 2010), which in turn increases the visibility of prey and possibly levels of predation. For example, the artificial light field around oil drilling platforms is sufficient to enhance fish foraging by increasing visibility of phototaxic prey that are attracted to the lights (Keenan et al. 2007).

During the site visit to the Clay Point salmon farm, large numbers of schooling baitfish, such as yellow-eyed mullet, were observed in the illuminated cage structures. It is apparent that the fish must enter cages at a small size and then become too large to exit the cage. It is noted that fish near the surface are more visible in an illuminated cage and that farm personnel also observe baitfish in the non-illuminated cages during daylight hours. At this time we are unable to confirm whether artificial lights lead to a greater abundance of fish other than salmon in the cages. However, there is some evidence that artificial lights do attract baitfish (McConnell et al. 2010); hence it is possible and likely that there will be a higher abundance of baitfish within illuminated cages than those without artificial lighting. It is also likely that night-time predation on baitfish by the salmon will also be higher due to an increase in prey visibility. Some predation on baitfish by salmon was observed during the night at the Clay Point salmon farm (C Cornelisen, pers. obs.). While the aggregation of baitfish and increased predation within the cage structures are likely to be enhanced by artificial lighting, these effects are
likely to be highly localised and of minor ecological significance because the salmon are fed an artificial diet and baitfish are released during harvest (see Section 5).

Attraction and aggregation of baitfish adjacent to illuminated cage structures could in turn enhance night-time predation by fish and marine mammals such as seals along the edge of the cages. For example, a study on feeding by harbour seals in a British Columbia river demonstrated that artificial lighting on bridges was partly responsible for enhanced night-time predation on salmon smolt (Yurk & Trites 2000). During the site visit to Clay Point, seals were observed around the cage structures throughout the period of sampling; however, they did not appear to congregate around any specific cage, including those that were illuminated \( i.e. \) we observed them around the dark cages as well as the illuminated cages. As in the case within the cages, artificial lighting will likely enhance the aggregation of some prey and predation within waters directly adjacent to the cages that are affected by the lights. As described in Section 3.2, the area affected by the lights is small and therefore the effects will be of little ecological significance within the context of the wider Marlborough Sounds ecosystem.

### 3.4. Vertical distribution of salmon and risk of parasitism

Submerged artificial lighting influences the vertical distribution of salmon within cage structures (Oppedal \( et al. \) 2001). As a result, lights can be used to control the depths used by the salmon and can assist in dispersing them over a larger volume of water during night-time hours (Juell \( et al. \) 2003; Juell & Fosseidengen 2004). However, increased densities of salmon at a given depth \( i.e. \) near the surface) due to artificial lighting have been shown to coincide with an increased risk of parasitism on salmon by copepods such as sea lice that are attracted by the lights (Heuch \( et al. \) 1995; Hevroy \( et al. \) 2003; Genna \( et al. \) 2005). Parasitism can result in increased fish mortality; hence, consideration of the effect of submerged artificial lighting on the depth distribution of salmon and the frequency and intensity of parasite infestations is of particular importance to the productivity of the farms. At present, native parasitic copepods such as sea lice are not problematic in the culture of King Salmon in New Zealand; however, they could become problematic under the use of artificial lighting if host switching occurs (Diggles 2011). The effects of artificial lighting on enhancing parasite risk to wild fish will likely be no more than minor and limited to those fish that aggregate around the submerged lights within the cage structures, such as baitfish.

### 3.5. Attraction of birds

It is possible that birds flying over the farm at night may become attracted to the lighted area, subsequently increasing their risk for collision and/or entanglement with farm structures. Such effects have been observed on fishing boats (Dick & Donaldson 1978; Rich & Longcore 2006) and on oil platforms (Wiese \( et al. \) 2001; Longcore & Rich 2004) and lighthouses (Jones & Francis 2003). It is noted that these documented effects of artificial lighting on birds are associated with elevated light structures. In the case of salmon farms, the artificial lights are
submerged beneath the water’s surface, and will likely have less influence on bird behaviour. The extent to which artificial lighting affects birds will depend on the types of resident birds and their nocturnal behaviours, and the routes of migratory birds that pass through the region on a seasonal basis and may be attracted to lighted areas. Birds that feed at night in the Marlborough Sounds, when the moon is half full, include gulls, prions and shearwaters (Sagar 2011). While these species could potentially be attracted to lighted areas, the diffuse nature of the submerged lighting is unlikely to attract any significant numbers of birds; hence the effect of lighting on seabirds is considered to be insignificant (Sagar 2011). It is noted that no seabirds were observed during the night sampling conducted at the Clay Point salmon farm.
4. EVALUATION OF EFFECTS AND THEIR SIGNIFICANCE

The effects of artificial lighting associated with the proposed farms will be limited to localised effects on organisms that inhabit the water column surrounding illuminated cage structures. Based on a review of the literature and observations made at the Clay Point salmon farm, the effects on small phototaxic organisms such as some zooplankton and phytoplankton will be limited to perhaps small, periodic increases in organism abundances within illuminated cages. All but one of the proposed farms will be situated in areas of deep water and high currents; hence any aggregations of small organisms within the illuminated cages will be temporary and limited to periods of low currents (*i.e.* slack tide).

The most likely effect of submerged artificial lighting associated with the proposed farms will be the enhanced attraction of some organisms, such as baitfish, during night hours. These fish could become trapped once they become too large to exit the cages through the mesh and then could be predated upon by the salmon. The level of predation on baitfish by salmon will depend on the life stage of the salmon within the cages and will be limited due to the fact that the salmon are fed an artificial diet. According to farm staff, baitfish trapped within the cage structures are also released during harvest. Regardless of artificial lighting, finfish farms are known to attract fish due to the presence of the structures as well as the generation of waste feed that is consumed by wild fish (*e.g.* Dempster *et al.* 2005; Forrest *et al.* 2007; Taylor & Dempster 2011).

It is acknowledged that the farm structures lie within a moving body of water and that the total volume of water (and associated organisms) affected by the lights will vary in time depending on currents. However, the currents themselves are likely to mitigate the extent to which the illuminated lights are able to attract and aggregate organisms. Furthermore, the total volume of the two Sounds combined is roughly 9,400 times the size of the total volume that will be occupied by the farms (based on a total area of 10 hectares (100,000 m$^2$) of surface area for 10 farms and a cage depth of 20 m). It is therefore highly unlikely that the farms would act as significant ‘sinks’ for organisms attracted to the lights. Based on the physical characteristics of the sites to be developed, the scale of the farms compared to the wider Sounds, and the small spatial footprint of the artificial lights, the effects of the artificial lighting on the surrounding ecosystem are likely to be no more than minor. In other words, while the effects of artificial lighting may be measureable at some level within the cage structures themselves, the effects in terms of the much larger marine ecosystem of the Marlborough Sounds will be very small and unlikely measureable. A summary of the issues and their magnitude of effects likely to arise from the use of artificial lighting on salmon farms is provided in Table 2.
Table 2. Summary of key issues and the magnitude of ecological effects likely to arise from artificial lighting. Effects described will be highly localised to individual farms due to the small spatial footprint of the artificial lighting.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Likely effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attraction of phototaxic organisms</td>
<td>Attraction of some zooplankton species is likely to occur; however, the effect will be no more than minor due to the small spatial footprint of the lights in comparison to the wider Sounds and the inability of small organisms to maintain their position within high currents.</td>
</tr>
<tr>
<td>Vertical migration and benthic settlement of planktonic organisms</td>
<td>Vertical migration in the water column by some phytoplankton and zooplankton species may be influenced within close proximity of the lights. These effects will be highly localised and positioning of the farms in high currents will most likely mitigate these effects.</td>
</tr>
<tr>
<td>Aggregation and visibility of prey and enhanced predation</td>
<td>There is likely to be an effect of artificial lights on wild fish over and beyond those associated with the structures and presence of feed. Visibility of prey during night time hours will also increase and in turn increase predation by adult salmon as well as fish and marine mammals (e.g. seals) outside the cages. These effects are likely to be highly localised because the salmon are fed an artificial diet.</td>
</tr>
<tr>
<td>Vertical distribution of salmon and risk of parasitism</td>
<td>Effects will be limited to those fish in close proximity to the lights and whose vertical distributions are affected by light levels, such as the salmon themselves. The main concern is in regard to reduced farm productivity. Increased parasitism on wild fish that occurs indirectly as a result of lighting will be limited to those within the footprint of the lights.</td>
</tr>
<tr>
<td>Attraction of birds</td>
<td>The effects of submerged artificial lights on seabirds will be insignificant (Sagar 2011).</td>
</tr>
</tbody>
</table>
5. CONCLUSIONS AND RECOMMENDED OPTIONS FOR MITIGATION AND MONITORING

The effects of submerged artificial lighting on the surrounding marine environment are likely to be highly localised and small in scale, both in terms of the physical effects on the underwater light environment and subsequent biological and ecological (e.g. food web) effects. The ‘footprint’ of the artificial lights will be mainly confined to the cage structures and to mid-water depths; hence organisms along the bottom or further than about 10 m from the cage structures are unlikely to be affected. The number and size of the farms in comparison to the wider ecosystem means that the effects on the surrounding ecosystem will be minor. Effects will likely be limited to the enhanced attraction and aggregation of some water column organisms such as baitfish.

Placement of the farms in areas of deep water and high currents will assist in mitigating attraction and aggregation of organisms within cage structures. To further minimise effects, efforts should be made to ensure that only the amount of lighting required for beneficial outcomes is used (i.e. unnecessary over-powering of lights should be avoided). This assessment included observations made during one site visit and it is likely that the effects of artificial lighting vary according to water column conditions. To further confirm that effects are of a small magnitude, we would recommend a follow-up site survey at a farm where lights are fully operational. An ‘observer’ approach to monitoring effects of artificial lighting under varying conditions is also recommended. Observations by farm staff could include noted changes in night-time feeding activity by fish, seabirds and marine mammals in and around the illuminated cages. In addition, inspection of gut contents during routine inspections of fish for disease and condition would assist in determining whether the salmon’s diet is subsidised by wild prey.
6. REFERENCES


Taylor P, Dempster T 2011. New Zealand King Salmon Plan Change: Effects of salmon farming on the pelagic habitat and fish fauna of the Marlborough Sounds and
management options for avoiding, remedying, and mitigating adverse effects. Report submitted to NZ King Salmon Ltd. 42 p.

