15 March 2017

ID: 1707

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Dear Stephanie

REVIEW OF SALMON FARM EFFECTS ON KING SHAG DIET

The Ministry for Primary Industries (MPI) have requested a review of a recent report by P.R. Taylor (2016) on the effects of salmon farming in the Marlborough Sounds on the prey of king shag, *Leucocarbo carunculatus*, and a paper by Keeley et al. (2015) on the recovery of benthic communities after fallowing and re-impact of salmon farms in Waihinau and Forsyth bays, Marlborough Sounds. The purpose of this review is to estimate at what point during the seabed recovery trajectory fallowed sites are likely to become feeding grounds for king shag prey species.

According to the most recent study of king shag feeding (Lalas and Brown 1998), in Pelorus Sound approximately 90 percent of their prey is witch flounder (*Arnoglossus scapha*), the other 10% being other flatfish species and various bottom-dwelling species (including opal fish). Earlier studies have, however, suggested a different mix of prey species, and Taylor (2016) explores two potential reasons for the apparent change in diet: species misidentification, and changes in prey availability due to increased fishing pressure. Taylor (2016) concludes that, while some species misidentification may have occurred in earlier studies (some 40-60 years earlier), in a 1971 study by Nelson (1971) common sole (*Peltorhamphus novaezelandiae*) was a major component of regurgitated meals, so it is possible that increased fishing pressure may be responsible for the shift in diet. However, Taylor (2016) stresses that the extent to which the increased fishing pressure is directly relevant to the Marlborough Sounds is questionable, as the resolution of the data did not allow region-specific analysis. The overall assessment was that king shags are generalist foragers, feeding mainly on bottom-dwelling fish, and in Pelorus Sound they currently feed primarily on witch flounder, with various other benthic fish species (including opal fish, common sole, and lemon fish) taken when possible (Taylor 2016).

Taylor (2016) also reviewed several diet studies of the various flatfish species that are preyed upon by king shags to determine their likely distribution relative to proposed relocation sites in

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the Marlborough Sounds. From his review of flatfish diets it is also possible to estimate the point along the benthic recovery trajectories of fallowed salmon farm sites where food items for witch flounder and other flatfish species are likely to return to fallowed sites. A recent paper by Keeley et al. (2015), provides an in-depth analysis of the infauna (animals living in the sediments) communities and their recovery trajectories following fallowing of the Waihinau farm site in 2009. This paper is used here as the best estimate of likely recovery times and trajectories for salmon farms in the Marlborough Sounds.

In the review of flatfish diet studies (Taylor 2016), witch flounder were found to be visual predators that prefer to eat a range of epifaunal species, including crabs and other crustaceans, and small pelagic fish. The biological material that falls from the salmon farm net pens includes many small crabs and crustaceans, and small pelagic fish are frequently observed around the sites proposed for relocation (D. Taylor pers. obs.). Even when farm sites are vacated, the epifaunal assemblage that has dropped from farm structures over time is likely to remain and provide feeding habitat for benthic-feeding fish species. Witch flounder have also been observed directly beside salmon pens in the Marlborough Sounds, so they are likely to move in and feed in and around the vacated farm areas. Based on the feeding ecology of this species, and personal observations of epifauna at these sites, I conclude that it is likely that witch flounder would return immediately to fallowed sites, as these are likely to represent fertile feeding grounds.

The other flatfish species identified as prey for king shags was lemon sole. This species is also considered a visual predator that feeds mainly on small crustaceans. Opal fish (probably *Hemerocoetes monopterygius*), the second most common prey item other than witch flounder, is also a visual feeder that preys upon small crustaceans. Due to the similarities in the diets of these benthic predatory fish, I conclude as I did for witch flounder, that these species are likely to return and begin feeding within vacated farm sites immediately after pens are removed.

The diets of most of the other benthic fish species (five out of the six species) in the feeding studies reviewed were found to differ depending on the highly adapted feeding morphologies and feeding behaviours of these non-visual predators (Taylor 2016). Of these species, only common sole has been listed as a king shag prey species. Common sole are nocturnal feeders, and depending on the study area have been found to feed mainly on infaunal polychaete worms, and small crustaceans. From Keeley et al. (2015), the abundance of polychaete worms is a key indicator and probably a key driver of the seabed recovery. Some species of polychaete worms, capitellid and dorvilleid polychaetes in particular, are tolerant of the highly nutrient enriched conditions found under salmon farms, and are likely to be present early in the fallowing process. According to Keeley et al. (2015), their abundance is likely to peak approximately 6-12 months after fallowing, as benthic condition improves (see Figure 1 below). This leads me to conclude that common sole are also likely also likely to return immediately to fallowed farm areas and may find these areas particularly fertile feeding grounds after 6 months of fallowing, as the abundance of their preferred prey type peaks.

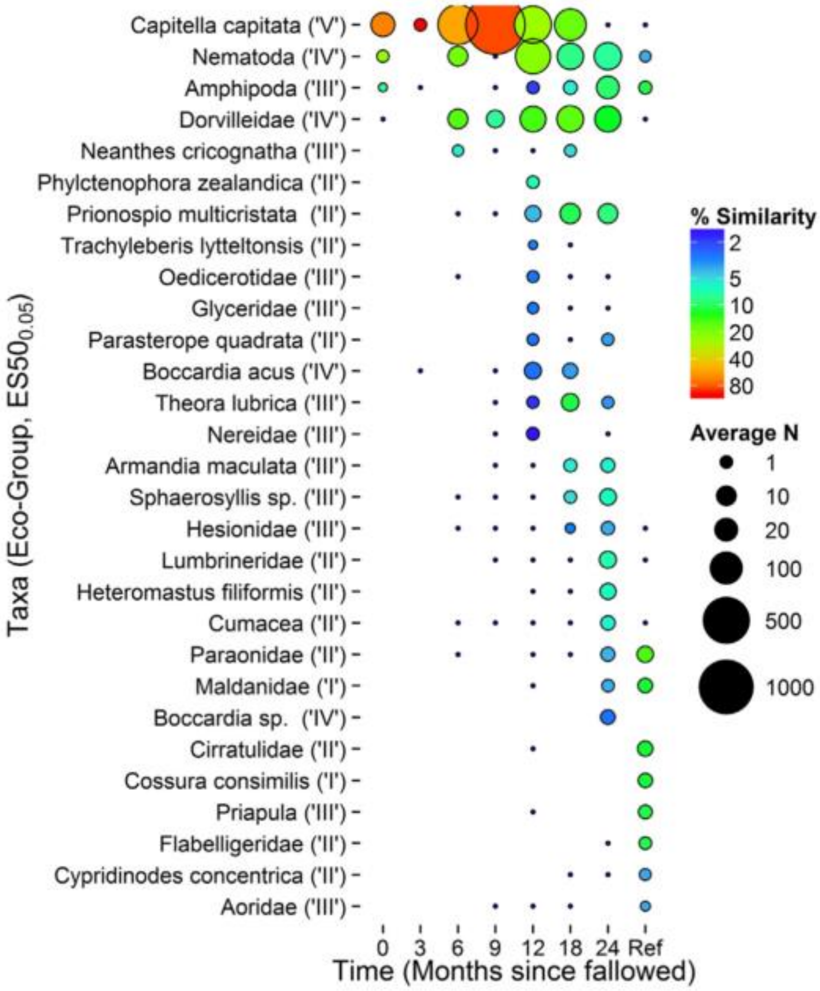

Figure 1. Bubble plot of the short term recovery of in the abundance of infauna species at Waihinau 0-24 months after fallowing. The plot shows species that contributed 90 percent of the similarity and they are sorted according to their relative contribution. Bubble size shows relative abundance. (Figure 5 from Keeley et al. (2015)).

Common reef fish species such as triplefins (Family Tripterygiidae) and jock stewart (*Helicolenus percoides*) may also be preyed upon by king shag (Lalas and Brown 1998). Triple fins (there are 26 species in New Zealand and all are endemic) are the most abundant reef fish in the shallow subtidal reef areas around New Zealand. They are visual predators that feed on a range of small mobile benthic crustaceans and other invertebrates. Jock stewart are common on rocky reef areas around New Zealand at depths of up to 1200 m. These fish are visual predators that feed on small fish, squid, and crustaceans. Because salmon farms are not sited over reefs, and monitoring to date (e.g. Dunmore et al. 2015) has found no adverse effects on nearby reef communities, the distribution and abundance of these species are unlikely to be negatively affected by salmon farm removal or relocation.

In summary, it would appear that, based on the diets of the main prey species of king shags, these benthic feeding fish species will likely immediately return to vacated farm sites, particularly visual feeders such as witch flounder, opal fish, triple fins, jock stewart, and lemon sole. As the farm sites recover the increase in abundance of infaunal polychaete worms, 6-12 months after the start of fallowing, is likely to provide fertile feeding grounds for common sole and other non-visual predatory flatfish species.

A potential limiting factor for the immediate return of benthic fish species to vacated sites would be if dissolved oxygen levels at the sediment / water interface dropped below 4 mg l^{-1} (Breitburg 2002). These sorts of levels could occur due to increased oxygen demand during the bacterial decomposition of enriched sediments. The most recent monitoring of the sites proposed for relocation found that DO levels approached 4.5 mg l^{-1} at the net pen edge of one of the sites, but at the remaining sites levels at the net pens were above 7 mg l^{-1}.

Yours sincerely,

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