Volume Two
May 2014

Appendix 28

Effects of total suspended solids on marine fish
(Page 2014b)

Chatham | Rock Phosphate Ltd

NIWA
Taihoro Nukurangi

Effects of total suspended solids on marine fish:

Pelagic, demersal and bottom fish species avoidance of TSS on the Chatham Rise

Prepared for Chatham Rock Phosphate

April 2014

Authors/Contributors:
Mike Page

For any information regarding this report please contact:

Mike Page
Marine Ecologist
Biodiversity and Biosecurity
+64-3-548 1715
m.page@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
217 Akersten Street, Port Nelson
PO Box 893
Nelson 7040
New Zealand

Phone +64-3-548 1715
Fax +64-3-548 1716

NIWA Client Report No:	WLG2014-7
Report date:	April 2014
NIWA Project:	CRP12303

Contents

Tables

Figures

Reviewed by

....

Approved for release by

....

Formatting checked by

Executive summary

There are few published studies on how estuarine and marine fish respond to total suspended solids (TSS) and even less known about behavioural thresholds. In situations where concentrations of TSS are not lethal, pelagic, demersal and bottom fish are likely to avoid (swim away from) higher levels of TSS.

Ocean Biogeographical Information System (OBIS) records show 63 fish species have been recorded within the licence area. Of these, 17 benthic and 46 demersal fish species are likely to encounter the predicted mining plume as modelled by Deltares (2014). Of these four species, ling, hake, hoki and giant stargazer have commercial value.

Overseas studies show that avoidance generally occurs at concentrations of approximately 3−5 mg/L for pelagic and demersal species. This concentration range is similar to the Australia and New Zealand Environment Conservation Council (ANZECC) guideline trigger turbidity of 2−3 mg/L in marine and estuarine waters. The avoidance threshold for benthic species appears higher, at greater than 50 mg/L.

A recent environmental impact study by FeBEC (2013b) on the link between Denmark and Germany, recommended an avoidance threshold of 10 mg/L for demersal species (e.g., Atlantic cod, herring and whiting), and 50 mg/L for benthic species (e.g., flatfish and eel).

Avoidance of the sediment plume on the Chatham Rise by pelagic, demersal and benthic species will occur in the immediate vicinity of the mining activity where concentrations of TSS are predicted to reach 100 mg/L. Avoidance may also occur for pelagic and demersal species when sediment concentrations in the plume exceed 3 mg/L, and are likely to occur at greater10 mg/L.

The determination of acceptable limits to TSS for juvenile and adult fish in CRP's phosphorite mining in licence PL50270 should be considered carefully as physiological tolerances and threshold levels are species- and life history-specific and have been determined only for a small number of species in experimental studies overseas.

1 Background

Chatham Rock Phosphate (CRP) have been granted a licence to prospect for nodules within a defined area on the Chatham Rise (Licence 50270) covering approximately 4726 km^2 in waters between depths of 350 and 450 m. CRP have also applied for a Mining License covering an area of 850 km^2 within the Prospecting License area. The licence area is located within part of the mid-Chatham Rise Benthic Protected Area (BPA), protected from fishing activities that involve trawling and dredging since November 2007 (Figure 1-1).

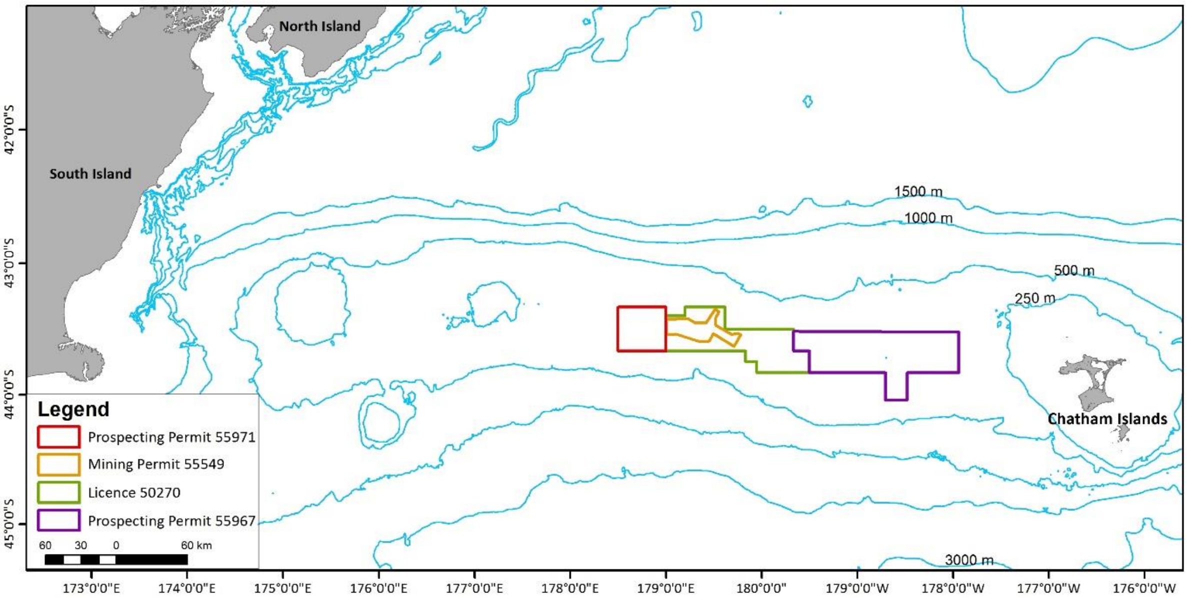


Figure 1-1: Location of Minerals Prospecting Licence 50270 area on the Chatham Rise. Mining Permit area 55549 and Prospecting Permit areas (55971 and 55967) are exploration permits not considered in this report.

The Chatham Rise bounds Subtropical (ST) and sub Antarctic (SA) water masses on the East Coast of the South Island. Their convergence forms the Subtropical Convergence (STC), a zone of mixing between the two water masses that is predominantly located along the crest of the ridge. Relatively high primary production is associated with this zone. Areas of high chlorophyll density are related to spatially and temporally variable localised upwelling (Bradford-Grieve, Boyd et al. 1999).

The Subtropical Convergence (STC) across the Chatham Rise supports diverse and productive pelagic and benthic ecosystems, driven by elevated levels of nutrients, and in-turn, phytoplankton productivity. Zooplankton and mesopelagic fish are abundant, along with demersal and mid-water fish on the northern and southern flanks of the ridge. This assemblage includes several valuable commercial fish species, dominated by hoki, ling and silver warehou (Bull, Livingston et al. 2001).

Bottom and mid-water trawling are the main fishing methods used on the Chatham Rise (Baird, Wood et al. 2009), with most trawling effort directed at hoki (*Macruronus novaezealandiae*), hake (*Merluccius australis*), ling (*Genyptrus blacodes*), silver warehou (*Seriolella brama*) and scampi (*Metanephrops challengeri*) (Table 1-1). In the area bounded by the CRP licence almost 90% of tows targeted hoki adjacent to the south-western boundary.

Silver warehou were targeted at the extreme south-eastern edge and hake to the north of the CHR at 180^{o} E (Beaumont and Baird 2010). Since 2002-03, trawl effort in the region has declined, with most fishing effort for hoki restricted to the south-west the licence area (Beaumont and Baird 2010).

At least 156 fish species are known to occur on or above the Chatham Rise (Bull, Doonan et al. 2001). Of these, thirty of the most common species that comprise 98% of the mean total catch rate from research trawls on the CHR are listed below (Table 1-1, Bull, Doonan et al. (2001)). Catches include demersal and benthic species living for all or part of their life on or near the seabed on the Chatham Rise. These fish are caught 5−10 m from the seafloor with a standardized bottom trawl and therefore represent species most likely to come into contact with a sediment plume from mining activity on the Chatham Rise (Deltares 2014). A table showing all species caught within the permit area is shown in Appendix 1.A modelling study by Deltares (2014) has predicted a sediment plume from mining activity to be typically less than 50 m above the seabed and to extend up to 20 km away from the activity at concentrations <10 mg/L TSS. Occasionally higher concentrations clay of up to 100 mg/L are predicted to occur in the immediate mining area. This activity is likely to have direct implications for both demersal and benthic fishes within the permit area, and in down-current locations.

This report investigates literature on the effects of TSS on marine adult and juvenile fish. We focus on behavioural responses to threshold levels of TSS as avoidance is likely to be the first response. However, lethal and sub-lethal thresholds are included for comparison. The review builds on an earlier report for CRP; WLG2012-61 (Page 2013), which investigated the effects of TSS on fish eggs and larvae.

2 Objectives

In December 2013, the National Institute of Water and Atmospheric Research (NIWA) Ltd was contracted by Chatham Rock Phosphate (CRP) to undertake a review of the effects of total suspended solids (TSS) on pelagic, demersal (near-bottom) and bottom fish with reference to the Chatham Rise or similar offshore ecosystems, both in New Zealand and overseas. Specifically, this report reviews published studies and reports examining the effects of total suspended solids (TSS) on juvenile and adult marine fish. The report includes lethal, sub-lethal and behavioural responses (avoidance and threshold responses), potential effects on predator-prey interactions and provides comment on the likely species-specific responses to TSS. Relevant published studies examining threshold responses of marine fishes overseas to TSS are compared by similar trophic groups to species known to occur within the CPR and that are most likely to be affected by the sediment plume modelled in CRP's PL50270 licence area on the Chatham Rise.

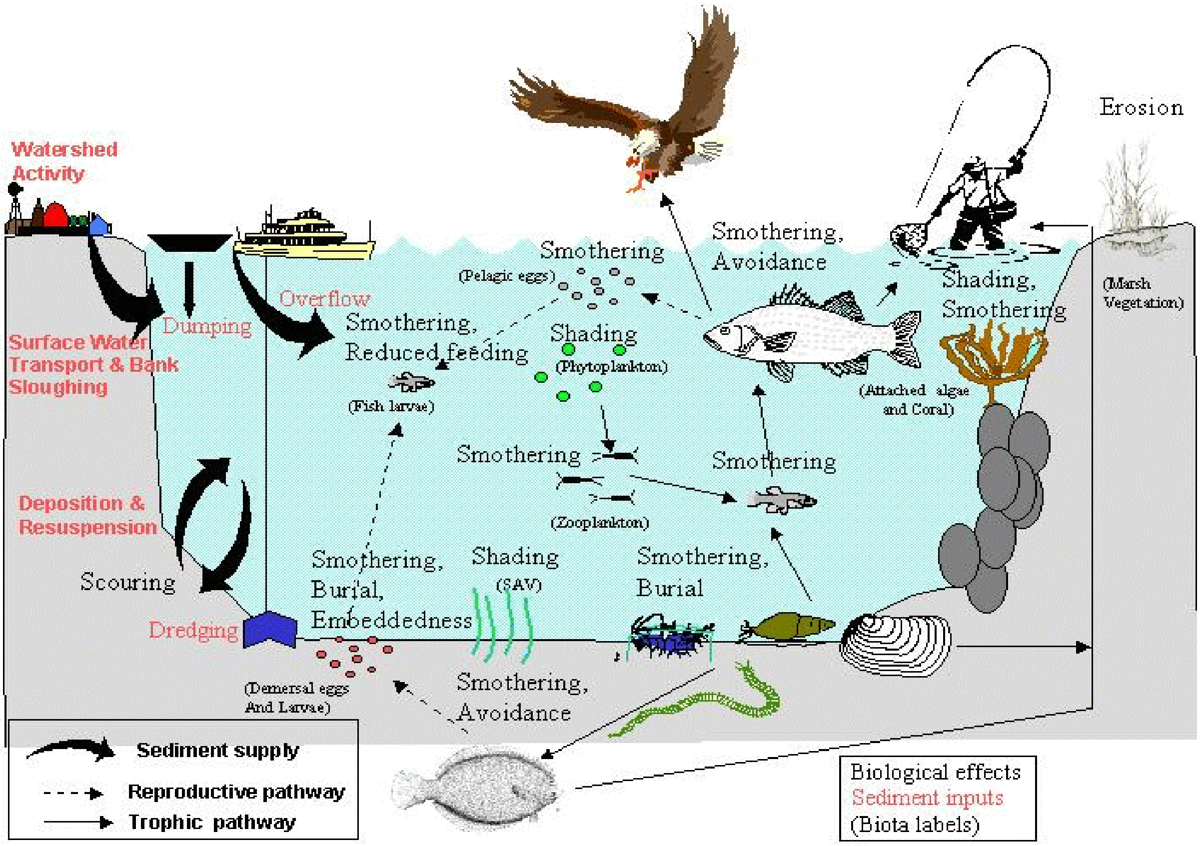
Table 2-1: Common demersal species caught in research bottom trawls on the Chatham Rise. Table adapted from Bull, Livingston et al. (2001); * species occurring in the prospecting licence area, distribution determined from maps in Hurst, Bagley et al. (2000). ▲ symbol represents species that migrate into mid-water, diurnally or for part of their life history.

Common name	Latin Name	Mean catch rate (kg/km^2)	Occurrence (%)
Hoki ▲	*Macruronus novaezealandiae* *	1225.3	97
Bollon's rattail	*Caelorinchus bollonsi*	85.7	88
Dark ghost shark	*Hydrolagus novaezealandiae* *	82.9	47
Ling	*Genypterus blacodes*	69.0	93
Black oreo	*Allocytus niger*	656.3	10
Javelinfish	*Lepidorhynchus denticulatus*	62.1	90
Lookdown dory	*Cyttus traverse* *	47.0	93
Silver warehou ▲	*Seriolella punctata* *	45.3	46
Alfonsinso ▲	*Breyx splendens* *	42.7	32
Spiny dogfish ▲	*Squalus acanthias* *	41.6	57
Pale ghost shark	*Hydrolagus* sp. *	34.1	68
Shovelnose spiny dogfish	*Deania calcea* *	26.2	32
Sea perch	*Heliocolenus* spp.	24.7	88
Giant stargazer	*Kathertostoma giganteum* *	22.7	62
Spiky oreo	*Neocyttus rhomboidalis*	22.1	18
Hake	*Merluccius australis* *	20.5	68
Silver dory ▲	*Cyttus novaezealandiae*	15.7	14
Oblique banded rattail	*Caelorinchus aspercephalus*	14.7	51
White warehou ▲	*Seriolella caerulea* *	14.2	42
Oliver's rattail	*Caelorinchus oliverianus*	9.1	53
Arrow squid ▲	*Nototodarus sloanii* *	8.9	63
Orange perch	*Lepidoperca aurantia*	8.6	14
Baxter's lantern dogfish	*Etmopterus baxteri*	7.1	15
Murphy's mackerel ▲	*Trachrurus murphyi* *	5.8	18
Barracouta ▲	*Thyristes atun*	5.7	12
Longnose velvet dogfish	*Centroscymnus crepidater*	5.3	7
Rudderfish ▲	*Centrolophus niger*	5.2	27
Long-nosed chimera	*Harriotta raleighana*	5.1	38
Red cod ▲	*Pseudophycis bachus* *	5.1	23
Baned bellowsfish	*Centriscops humerosus*	4.7	56

3 Total suspended sediment thresholds on fish

Suspended sediments increase turbidity, directly affecting fish by reducing visibility of pelagic food and clogging gills with associated acute and chronic impacts such as immediate physiological stress, reduced growth rates and reproductive fitness.

The biological effects of total suspended solids can be summarized in a general conceptual model (Figure 3-1) by Berry, Rubenstein et al. (2003). The effects of TSS on species in some habitats are better studied than others. There is a relatively large body of literature relating to freshwater ecosystems and salmonids (Kerr 1995), but considerably less for estuarine ecosystems (Newcombe and Jensen 1996; Clarke and Wilber 2000) and very few in marine ecosystems, particularly for offshore ecosystems such as the Chatham Rise. Most studies on



the effects of TSS on marine fish are tabled in FeBEC (2013b).

Figure 3-1: Conceptual model of biological effects of suspended and bedded sediments in estuaries. Source: Berry, Rubenstein et al. (2003).

Newcombe and Jensen (1996) summarized much of the available data on the effects of suspended sediment on freshwater and estuarine fishes and fitted empirical models based on the degree and duration of exposure. Responses by fish fishes to suspended sediments occur on a range of levels (Table 3-1).

Table 3-1: Scale of the severity of ill effects associated with excess suspended sediment. Source: Newcombe and Jensen (1996).

Severity of effect	Description of effect
	Nil effect
0	No behavioural effects
Behavioural effects	
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response (moves away?)
Sub-lethal effects	
4	Short-term reduction in feeding success
5	Minor physiological stress
6	Moderate physiological stress
7	Moderate habitat degradation
8	Major physiological stress; long-term reduction in feeding, poor condition
Lethal and para-lethal effects	
9	Reduced growth rate, fish density; delayed hatching
10-14	0 -100% mortality

In the review by Newcombe and Jensen (1996), effects were scored on a qualitative 'severity of ill effect' scale (Table 3-1). Here, mild effects are seen at low TSS, from short-term exposures and as the intensity and duration of exposures increase, chronic sub-lethal and lethal effects are manifested. The timing of the exposure is also very important, affecting different life-history stages in different ways. For example, Engell-Sørensen and Skyt (2002) suggest that early life history stages are likely to be more vulnerable to lower concentrations of TSS than for juveniles and adults. This difference is reflected by the sensitivity of egg chorion to smothering by adherence of sediment grains (FeBEC 2013b) and abrasion to the body surface of larvae (Johnston and Wildish 1981). Gills of larvae are particularly sensitive to clogging. (Partridge and Michael 2010) found the tolerance of snapper (*Pagrus auratus*) larvae to calcarenite dredge material reduced significantly when their mouths opened for feeding. Duration of exposure is also likely to be critical. A review of exposure levels by Berry, Rubenstein et al. (2003), found that high levels of suspended sediment for a short time maybe less of a problem than persistently long chronic exposure to TSS. High turbidity for short periods of time cause fish to abandon cover and avoid the sediment plume. Exposure for longer duration causes sub-lethal physiological effects such as increased respiration rates in response to oxygen depletion of clogged gills, and reduced feeding rates leading to slower growth. Mortality occurs when fish are exposed to high concentrations for a long period of time (Figure 3-2).

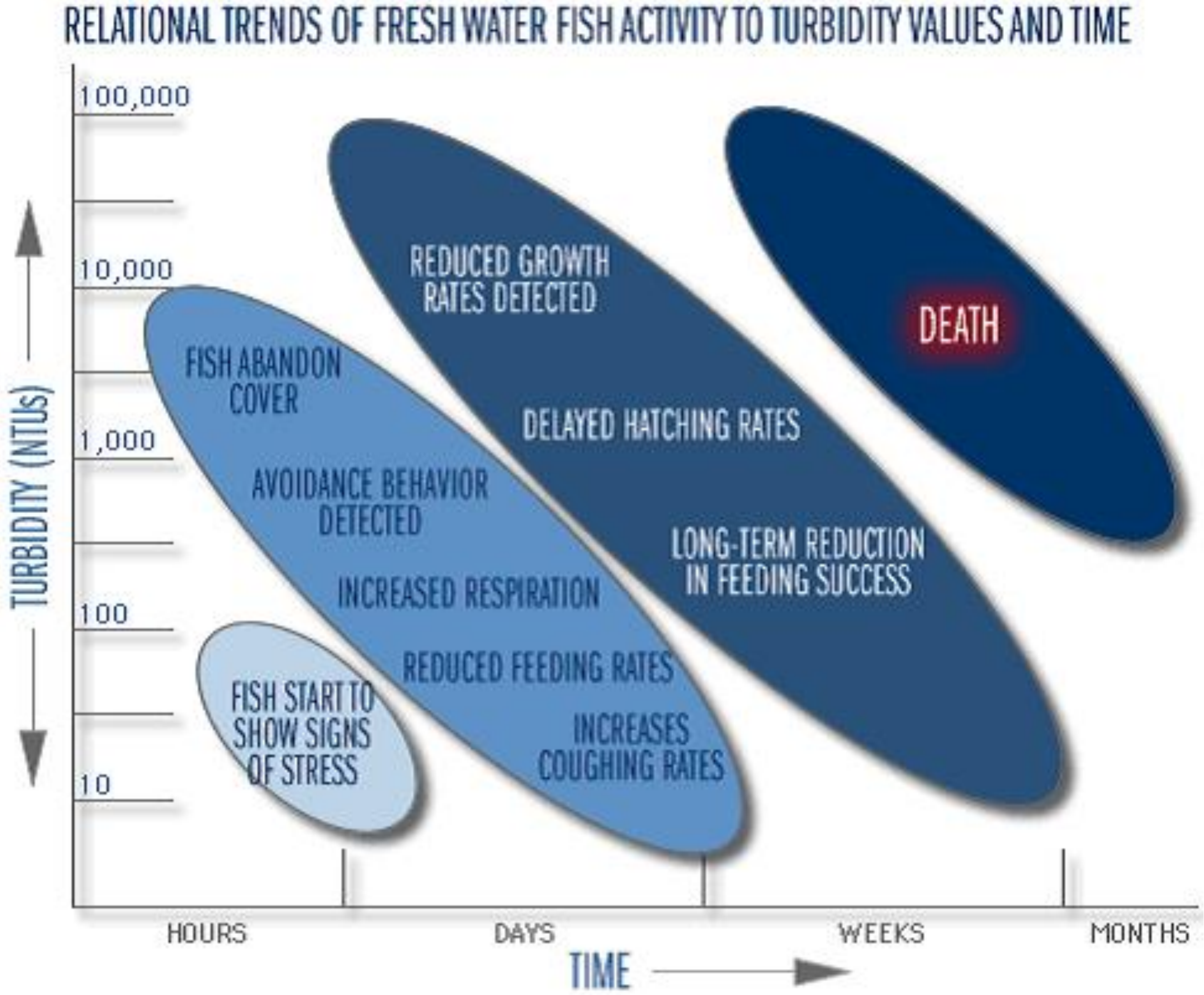


Figure 3-2: Idealized model of fish response to increased suspended sediment. Schematic diagram adapted from Newcombe and Jensen (1996), source of the figure is unknown, cited in (Berry, Rubenstein et al. (2003); FeBEC (2013b)).

Unlike sedentary species and early life stages, juvenile and adult fishes are generally capable of swimming away from areas where environmental conditions deteriorate. As a consequence, potentially lethal and or persistent TSS levels are less likely to lead to mortality events among juvenile and adult fish. Sensitivity to suspended sediment varies greatly between species and between life history stages, and depends on sediment composition (particle size and angularity), concentration and duration of exposure (Newcombe and Jensen 1996).

Wilber and Clarke (2001) also reviewed data on suspended sediment focusing on impacts of dredging operations on estuarine organisms. They plotted estuarine fish data separately from freshwater and salmonid fish to show how little data there were for estuarine and marine fishes. Most studies undertook short duration tests at very high exposures (Figure 3-3).

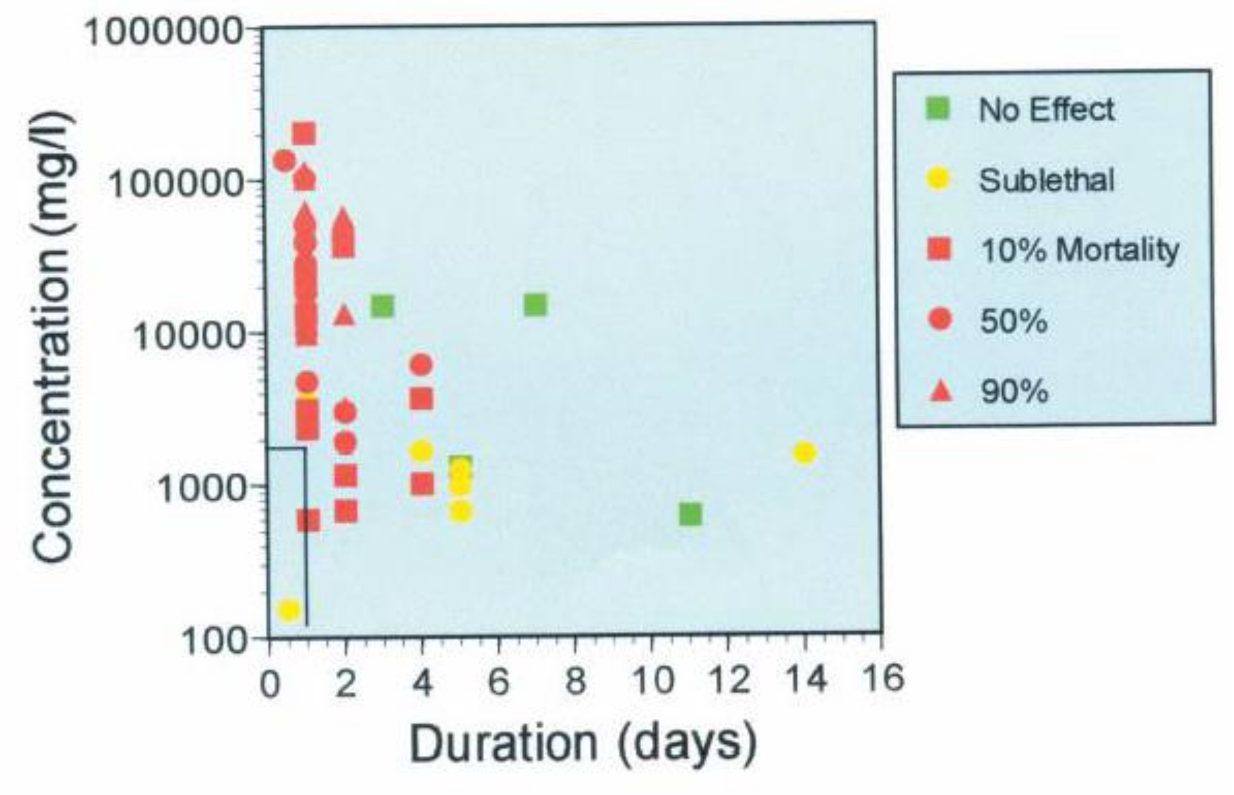


Figure 3-3: Responses of non-salmonid and estuarine adult fish to suspended sediment concentrations. The area in rectangles depicts a probable dosage range associated with most dredging operations. Source FeBEC (2013b) adapted from Wilber and Clarke (2001).

In 2013 Environmental Impact Assessment on the Fehmarnbelt Link between Denmark and Germany (FeBEC 2010; FeBEC 2013a; FeBEC 2013b) undertook a comprehensive review of current literature. They carried out sediment dose-response experiments on commercial benthic, demersal and pelagic fish species and recommended threshold values based on avoidance behaviour studies.

3.1 Behavioural and physiological responses and trophic effects of TSS

3.1.1 Behavioural effects

Threshold levels are determined by the concentration of suspended solids, usually expressed in milligrams per litre (mg/L) that must be exceeded for a given response to occur. For example, lethal thresholds are the concentration at which 10, 50, or 100% of experimental animals are killed after a pre-determined exposure time. Behavioural responses are often experimentally determined in choice experiments where fish are offered a choice between clear and turbid water.

Herring, for example, display avoidance behaviour when encountering sediment plumes of equally-sized particles of clay or lime concentrations of between 2 mg/L and 8-9 mg/L, respectively when the background concentration was less than 0.4 mg/L (Appelberg, Holmqvist et al. 2005) in (FeBEC 2013b). Similarly, Johnston and Wildish (1981) recorded avoidance of 9-12 mg/L dredge spoil by juvenile herring in the Miramichi Estuary in New Brunswick. Wildish, Wilson et al. (1977) found a slightly higher threshold for adult herring in fine sediment of 19 ± 5 mg/L, and 35 ± 5 mg/L in coarse sediment. Herring larvae show sub-lethal effects at slightly lower concentrations (Messieh, Wildish et al. 1981; FeBEC 2010).

Table 3-2: Published physiological and behavioural responses to threshold concentrations of total suspended solids. Larval, juvenile and adult marine and estuarine fishes.

Common name/ species	Life stage	Threshold concentration on sedimentation	Effect: avoidance behaviour/lethal/sub-lethal effects	References
Demersal species				
Atlantic Cod *Gadus morhua*	Juvenile	Turbidity	No strong effect on habitat preference	Meager and Utne-Palm (2008)
	Adult	550 mg/L (1d – 10d exposure)	No mortality, some reversible morphological changes in gill epithelium occurred	Humborstad, Jorgensen et al. (2006)
	Adult	3-5 mg/L	Avoidance behaviour	Appelberg, Holmqvist et al. (2005) in FeBEC (2013b)
	Adult	3 mg/L	Avoidance behaviour in experimental flume	Westerberg, Rönnbäck et al. (1996)
	Juvenile & Adult	10 mg/L	Threshold value for avoidance behaviour	FeBEC (2013b)
Snapper (*Pagrus auratus*)	Larvae	4 mg/L	First Observable Effect Concentration	(Partridge and Michael 2010)
	Larvae	156 mg/L	50% mortality after 12 h	(Partridge and Michael 2010)
	Juvenile	20 NTU	Significant decline in foraging success after 1 h	(Lowe 2013)
	Juvenile	40 NTU	30 d exposure, maximum weight loss of 14% reached	(Lowe 2013)
	Juvenile	35 mg/L	Altered foraging strategies	(Lowe 2013)
Pelagic species				
Japanese Horse mackerel *Trachiurus japonicus*	Adult	5 mg/L	Threshold value for avoidance behaviour	Morinaga, Koike et al. (1988) in Westerberg, Rönnbäck et al. (1996)
Herring (Atlantic) *Clupea harengus*	Larvae	3 mg/L	Reduced feeding rate	Messieh, Wildish et al. (1981)
	Larvae	540 mg/L	Significantly reduced growth rates	Messieh, Wildish et al. (1981)
	Juvenile	9-12 mg/L	Avoidance behaviour	Johnston and Wildish (1981)
	Juvenile	20 mg/L	Reduced feeding rate	Johnston and Wildish (1982)
	Juvenile	9.5-12 mg/L	Avoidance behaviour	FeBEC (2013b)
	Adult	19 ± 5 mg/L fine sediment	Avoidance behaviour	Wildish, Wilson et al. (1977) in FeBEC

Common name/ species	Life stage	Threshold concentration on sedimentation	Effect: avoidance behaviour/lethal/sub-lethal effects	References
		and 35 ± 5 mg/L coarse sediment		(2013b)
	Adult	3-5 mg/L	Avoidance behaviour	Appelberg, Holmqvist et al. (2005) in FeBEC (2013b)
	Juvenile & Adult	10 mg/L	Threshold value for avoidance behaviour	FeBEC (2013b)
	Larvae	2 mg/L	Decreasing trend in Standard Length with coarse sediment	FeBEC (2010)
Benthic species				
Flatfish spp.	Larvae	Reduced light intensity	Reduced food intake	Blaxter (1969) in FeBEC (2013b)
Plaice *Pleuronectes platessa*	Adult	3,000 mg/L	No mortality among plaice for 14 days exposure	(Keller, Lüdemann et al. 2006) in (FeBEC 2013b)
Estuarine/Neritic species				
Atlantic silverside *Menidia*	Adult	580* mg/L	10% mortality after 24hr exposure	Sherk, O'Connor et al. (1975)
Anchovy *Anchoa mitchilli*	Adult	2310 mg/L	10% mortality after 24hr exposure	Sherk, O'Connor et al. (1975) in Newcombe and Jensen (1996)
Coastal/anadromous species				
Bass (striped) *Morone saxatilis*	Adult	1,500 mg/L	Plasma & Haemocrit increased	Sherk, O'Connor et al. (1975) in Newcombe and Jensen (1996)
Coastal species				
Cunner *Tautogolabrus adspersus*	Adult	28,000 mg/L	50% mortality after 24hr exposure	Rogers (1969) in Newcombe and Jensen (1996)

*LC_{10} cited incorrectly in Newcombe and Jensen (1996) and Humborstad, Jorgensen et al. (2006) as 58 mg/l

Two independent studies on avoidance behaviour for adult Atlantic cod found similar avoidance responses when dose duration was increased. For example, studies by both Appelberg, Holmqvist et al. (2005) and Westerberg, Rönnbäck et al. (1996) found avoidance behaviour to occur at a threshold concentration of 3 mg/L. The Japanese horse mackerel, (*Trachiurus japonicas*), a pelagic species, also demonstrated avoidance behaviour at 5 mg/L, a concentration threshold similar to Atlantic cod and herring (Morinaga, Koike et al. 1988) (Table 3-2).

3.1.2 Sub-lethal effects

All other studies found used dose-response experiments to determine sub-lethal/lethal rather than avoidance thresholds. Benthic and estuarine species appear to be more tolerant to suspended sediment (FeBEC 2013b). Plaice (*Pleuronectes platessa*), for example, survived TSS concentrations of 3000 mg/L (Keller, Lüdemann et al. 2006) in FeBEC (2013b). Two estuarine species, the Atlantic silverside (*Menidia menidia*) and anchovy (*Anchoa mitchilli*) had thresholds of 580 mg/L and 2300 mg/L, respectively to suspended Fuller's earth. Previous studies (Newcombe and Jensen 1996; Humborstad, Jorgensen et al. 2006; FeBEC 2013b) identified the Atlantic silverside as being highly sensitive to suspended sediment incorrectly cited the threshold concentration an order of magnitude lower (58 mg/L) than determined in the original study (Sherk, O'Connor et al. 1975).

Coastal (nearshore demersal) and anadromous species also appear to have higher tolerance to TSS than demersal and pelagic fishes. Striped bass (*Morone saxatilis*), a species that migrates to freshwater for part of its life history, had increased levels of plasma and haemocrit in response to 1,500 mg/L natural sediment (Sherk, O'Connor et al. 1975). Similarly cunner (*Tautogolabrus adspersus*), a coastal species of wrasse, had 50% mortality at 28,000 mg/L (Sherk, O'Connor et al. 1975).

3.1.3 Respiration

If sediment particles are caught in or on gills, gas exchange with the water is reduced leading to oxygen deprivation (Essink 1999; Clarke and Wilber 2000). This effect is greatest for juvenile fish as they have small easily clogged gills and higher oxygen demand (FeBEC 2010). For example, juvenile snapper (*Pagrus auratus*) show a positive relationship between increased suspended sediment loads and epithelial hyperplasia/fusion of lamellae. This causing coughing and gulping in turbid conditions (Lowe 2013). Species belonging to the family Clupeidae; Atlantic herring, sprats (*Sprattus* spp.) and pilchards (*Sardinops neoplichardis*) are particularly vulnerable to gill clogging because of their long, densely-spaced gill-rakers (Engell-Sørensen and Skyt 2002). Pathological changes have also been shown for gill lamellae of Atlantic cod exposed to high concentrations of mud. Although hypertrophy and hypoplasia of the gill epithelium occurred, no mortality was observed (Humborstad, Jorgensen et al. 2006).

3.1.4 Reduced visibility and feeding

Visual predators can be hindered by increased turbidity by several factors. Some are related to the predator such as a changes in reactive distance locating prey (FeBEC 2013b). Other factors relate to the prey size and escape chances in more turbid water (de Jong, Essink et al. 1993). For example, increased turbidity and attack speed was found to reduce the escape success among juvenile cod in laboratory experiments (Meager and Utne-Palm 2008).

If persistent, decreased feeding success among juvenile fish may influence survival, year-class strength, recruitment and overall condition (Wilber and Clarke 2001). Lowe (2013) recorded a decrease in snapper Relative Condition Index with increasing suspended sediment loads. This relationship was supported by a decline in foraging success with increasing turbidity. Feeding strategies may change in turbid waters, as suggested by differences in the stomach contents of the visual predator *Elops machnata* in different turbidity conditions (Hecht and van der Lingen 1992). Changes in water clarity have also been claimed to affect the schooling ability of species such as herring and other clupeids using visual schooling cues (Appleby and Scarratt 1989).

Furthermore, broader ecosystem effects should be considered in relation to TSS in the water column. Mesopelagic fishes and cephalopods have high ecological importance in the Chatham Rise ecosystem (Pinkerton 2013). Thus any small change in these groups will cause large changes in other groups such as demersal and benthic fishes. However, the probability that mesopelagic species will be influenced by a sediment plume 50 m from the seafloor as modelled by (Deltares 2014) is relatively low.

3.1.5 Reproduction

A preferred habitat can be highly altered by substrate removal or by sedimentation, affecting species that depend on certain bottom substrates for nursery, spawning and feeding. Moles and Norcross (1995) cited in FeBEC (2013b) found a strong correlation between grain size and sediment type for flatfish species. Other benthic species such as sandeels (F. Ammodytidae) prefer very coarse grain sizes (FeBEC 2013b). Skate and ray species along with other oviparous elasmobranch species known to lay egg cases are also susceptible to suspended sediment blocking the respiratory fissures or horns (Velterop 2011). The spawning behaviour of squid has a large visual component and increased turbidity may also cause movement away from a sediment plume altering spawning output and predator prey dynamics (N. Moltschaniwskyj, pers. comm.).

A change in sediment composition can negatively affect reproduction success. Various studies have shown that changes in sediment that serve as spawning grounds either prevent fish from spawning or cause them to lay eggs in less optimal areas (de Groot 1980). A total of 17 benthic and 46 demersal or pelagic species have been recorded within the boundary of the CRP licence area (Appendix 1). Little is known about the reproductive behaviour of these species. However, the presence of ripe, running-ripe and recently spawned fish in trawl research surveys (O'Driscoll, Booth et al. 2003) in the vicinity of the licence area suggests that ling (*Genypterus blacodes*), hake (*Merluccius australis*), silver warehou (*Seriolella punctata*) and giant stargazer (*Kathetostoma giganeum*) spawn in the vicinity of the licence area, whereas hoki (*Macruronus novaezealandiae*) migrate north to Cook Strait to spawn.

Giant stargazer are probably benthic spawners. Anecdotal evidence suggests that ling may also lay eggs on the seabed. The life history of non-commercial species in the region is unknown, however many are likely to spawn on or near the seabed. Burial of these eggs would likely cause mortality. The effects of TSS on pelagic eggs is discussed in an earlier report (Page 2013).

The comparison of published threshold values for fish species is also problematic, as different experimental studies may use different sediment types (i.e., different grain sizes and angularity of particles), record different units of turbidity (PSU versus concentration mg/L), and measure different response parameters (behavioural, physiological (sub-lethal), versus lethal effects).

4 Species avoidance thresholds to TSS concentration

Responses to suspended solids are likely to be species-specific and dependent on individual life-history. To our knowledge no information on responses to TSS exists for species that occur on the Chatham Rise. Some broad level comparisons can however be made based on relatively few overseas studies on avoidance behaviour thresholds.

Demersal and pelagic species (Atlantic cod and mackerel) appear to avoid TSS at concentrations of approximately 3–5 mg/L (Tables 3-2 and 4-1). This concentration range is similar to the Australia and New Zealand Environment Conservation Council (ANZECC) guideline trigger turbidity of 2–3 mg/L in marine and estuarine waters, cited in Partridge and Michael (2010). The avoidance response of Atlantic herring is more variable because adults appear more tolerant than juvenile fish.

Table 4-1: Published data on fish species responses to total suspended solids. Related species in New Zealand.

Species with published data on avoidance thresholds to TSS (data from Table 3-2)				Related species in New Zealand	
Common name	**Species**	**Family**	**TSS avoidance threshold**	**Species in NZ**	**Common name(s)**
Atlantic herring	*Clupea harengus*	Clupeidae	2−30 mg/L	*Spratttus* spp. *Sardinops neopilchardis*	Sprats Pilchards
Atlantic cod	*Gadus morhua*	Gadidae	3 mg/L	*Micromesistus australis*	Southern blue whiting
Japanese horse mackerel	*Trachiurus japonicus*	Carangidae	5 mgL	*Trachrurus* spp.	Horse mackerel Murphy's mackerel Jack mackerel
Plaice	*Pleuronectes platessa*	Pleuronectidae	-	*Peltotretis flaviatus* *Peltohampus* spp.	Lemon sole Common and slender sole
Atlantic silverside	*Menidia*	Antherinopsidae	-	None	-
Anchovy	*Anchoa mitchilli*	Eugraulidae	-	*Eugraulis australis*	Anchovy
Bass (striped)	*Morone saxatilis*	Moronidae	-	None	-
Cunner	*Tautogolabrus adspersus*	Labridae	-	*Notolabrus* spp.	Wrasses,

Higher thresholds for avoidance were determined for the construction of the Fehmambelt link, FeBEC (2013b). An acceptable threshold of 10 mg/L was recommended for the demersal and pelagic species; Atlantic cod (*Gadus morhua*), whiting (*Merlangius merlangus*), herring (*Clupea harengus*) and European sprat (*Spratus spratus*) and 50 mg/L for benthic species of flatfish, European eel (*Anguilla Anguilla*), sea stickleback (*Spinachia spinachia*) and snakeblenny (*lumpenus lampretaeformis*). The threshold concentration responses of related New Zealand species on the Chatham Rise to TSS may be similar to the northern hemisphere species studied. Herring are closely related to sprats, pilchards and anchovies that are important prey for larger pelagic and coastal species. The Atlantic cod is a relative of the New

Zealand southern blue whiting that is present in the licence area, and Murphy's mackerel (*Trachurus murphyi*) has also been caught in the region.

Deltares (2014) predict the sediment plume from mining to extend up to 20 km away from the activity at concentrations varying from 0.1 to 10 mg/L TSS, depending on timing of the mining activity. This concentration range is within the threshold TSS of 3 – 10 mg/L for avoidance behaviour of demersal and pelagic species, but is lower than the concentration threshold of 50 mg/L for benthic species recommended by (FeBEC 2013b). Therefore, demersal species in the region of the sediment plume may avoid the mining area for a distance of 20 kilometres. Higher concentrations clay of up to 100 mg/L that occur in the immediate mining area will certainly cause fish migration.

In conclusion, predicting avoidance response thresholds of juvenile and adult fishes to a sediment plume on the Chatham Rise is based on broad comparisons with studies on species in overseas ecosystems. Experimental and field studies would be required to inform acceptable limits to mining activity with a degree of certainty.

5 References

Appelberg, M., Holmqvist, M., Lagenfelt, I. (2005) Øresundsforbindelsens inverkan paa fisk och fiske, Underlagsrapport 1992-2005: 230.

Appleby, A.D., Scarratt, D.J. (1989) Physical effects of suspended solids on marine and estuarine fish and shellfish, with special reference to ocean dumping: a literature review. *Canadian Technical Report of Fisheries and Aquatic Sciences*, Report no. 1681: 30.

Baird, S.J., Wood, B.A., Bagley, N.W. (2009) Nature and extent of commercial fishing effort on or near the seafloor within the New Zealand 200 n. mile Exclusive Economic Zone, 1989-90 to 2004-05. *Draft New Zeland Aquatic Environment and Biodiversity Report*, Prepared for the Ministry of Fisheries: 48.

Beaumont, J., Baird, S. (2010) Phosphorite prospecting on the Chatham Rise - biological and commercial fishing considerations. *NIWA Client Report*, WLG2010-27: 45.

Berry, W., Rubenstein, N., Melzian, B., Hill, B. (2003) The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems: A Review. *Internal report to US EPA, Office of Research and Development, National Health and Environmental Effects Laboratory*: 58.

Blaxter, J.H.S. (1969) Visual Threshold and Spectral Sensitivity of flatfish larvae. *Journal of experimental Biology*, 51: 221-230.

Bradford-Grieve, J.M., Boyd, P.W., Chang, F.H., Chiswell, S., Hadfield, M., Hall, J.A., James, M.R., Nodder, S.D., Shushkina, E.A. (1999) Pelagic ecosystem structure and functioning in the Subtropical Front region east of New Zealand in austral winter and spring 1993. *Journal of Plankton Research*, 21(3): 405-428. DOI 10.1093/plankt/21.3.405

Bull, B., Doonan, I., Tracey, D., Hart, A. (2001) Diel variation in spawning orange roughy (Hoplostethus atlanticus, Trachichthyidae) abundance over a seamount feature on the north-west Chatham Rise. *New Zealand Journal of Marine and Freshwater Research*, 35(3): 435-444. <Go to ISI>://000172298700002

Bull, B., Livingston, M.E., Hurst, R., Bagley, N. (2001) Upper-slope fish communities on the Chatham Rise, New Zealand, 1992-99. *New Zealand Journal of Marine and Freshwater Research*, 35(4): 795-815. <Go to ISI>://000173845300013

Clarke, D.G., Wilber, D. (2000) Assessment of potential impacts of dredging operations due to sediment resuspension. *DOER Technical Notes Collection (ERDCTN-DOER-E9)*, U.S. Army Engineer Research and Development Center, Vicksburg, MS 14. www.wes. army, mil/el/dots/doer

de Groot, S.J. (1980) The consequences of marine gravel extraction on the spawning of herring *Clupea harenus* Linne. *Journal of Fish Biology*, 16(6): 605-611.

de Jong, V.N., Essink, K., Boddeke, R. (1993) The Dutch Wadden Sea: a changed ecosystem. *Hydrobiologia*, 265(1-3): 45-71.

Deltares (2014) Modelling investigations on mine tailing plume dispersion on the Chatham Rise *Report prepared by Deltares for Chatham Rock Phosphate Ltd*, Delatres Report 1209110-000-ZKS-007: 72.

Engell-Sørensen, K., Skyt, H.P. (2002) Evaluation of the Effect of Sediment Spill from Offshore Wind Farm Construction on Marine Fish, Report prepared by Bioconsult: 18.

Essink, K. (1999) Ecological effects of dumping of dredged sediemnts; options for management. *Journal of Coastal Conservation*, 5: 69-80.

FeBEC (2010) Sediment Dose Response Study. *Technical Report. Prepared for Femern A/S*, Doc. No. E4-TR-036.: 147.

FeBEC (2013a) Commercial Fisheries in Fehmarnbelt. Environmental Impact assessment Report, Report no. E4TR0042 – Volume II: 181.

FeBEC (2013b) Fish Ecology in Fehmarnbelt. Environmental Impact assessment Report, Report no. E4TR0041 - Volume I: 254.

Hecht, T., van der Lingen, C.D. (1992) Turbidity induced changes in feeding strategies of fish in estuaries. *South African Journal of Marine Science-Suid-Afrikaanse Tydskrif Vir Seewetenskap*, 27: 95-107.

Humborstad, O.-B., Jorgensen, T., Grotmol, S. (2006) Exposure of cod Gadus morhua to resuspended sediment: an experimental study of the impact of bottom trawling. *Marine Ecology Progress Series*, 309: 247-254. 10.3354/meps309247

Johnston, D.W., Wildish, D.J. (1981) Avoidance of dredge spoil by herring (Clupea harengus harengus). *Bulletin of Environmental Contamination and Toxicology*, 26(1): 307-314. 10.1007/BF01622095

Johnston, D.W., Wildish, D.J. (1982) Effect of suspended sediment on feeding by larval herring (Clupea harengus harengus L.). *Bulletin of Environmental Contamination and Toxicology*, 29(3): 261-267.

Keller, O., Lüdemann, K., Kafemann, R. (2006) Lterature review of offshore wind farms with regard to fish fauna. *BfN-Skripten*, Vol. 186: 47-130.

Kerr, S.J. (1995) Silt, turbidity and suspended sediments in the aquatic environment: an annotated bibliography and literature review. *Ontario Ministry of Natural Resources, Southern Region Science & Technology Transfer Unit* Technical Report TR-008: 277.

Lowe, M.L. (2013) Factors affecting the habitat usage of estuarine juvenile fish in northern New Zealand. *Doctor of Philosophy in Marine Science*. University of Auckland, Auckland: 238.

Meager, J.J., Utne-Palm, A.C. (2008) Effect of turbidity on habitat preference of juvenile Atlantic cod, Gadus morhua. *Environmental Biology of Fishes*, 81(2): 149-155. DOI 10.1007/s10641-007-9183-z

Messieh, S.N., Wildish, D.J., Peterson, R.H. (1981) Possible impact from dredging and spoil disposal on the Miramichi Bay herring fishery. *Canadian Technical Report on Fisheries and Aquatic Science. 1981.*, 1008: 33.

Moles, A., Norcross, B.L. (1995) Sediment preference in juvenile Pacific flatfishes. *Netherlands Journal of Sea Research*, 3(1-1): 177-182.

Morinaga, T.T., Koike, T., Ootomo, K., Matsuike, K. (1988) Response of a fish school to turbid water. *Uni-Mer*, 26: 19-28.

Newcombe, C.P., Jensen, J.O.T. (1996) Channel Suspended Sediment and Fisheries: A Synthesis for Quantitative Assessment of Risk and Impact. *North American Journal of Fisheries Management*, 16(4): 693-727. 10.1577/1548-8675(1996)016<0693:cssafa>2.3.co;2

O'Driscoll, R.L., Booth, J.D., Bagley, N.W., Anderson, O.F., Griggs, L.H., Stevenson, M.L., Francis, M.P. (2003) Areas of importance for spawning, pupping or egg laying, and juveniles of New Zealand deepwater fish, pleagic fish and invertebrates. *NIWA Technical Report*: 102.

Page, M.J. (2013) Phosphorite prospecting on the Chatham Rise: Effects of total suspended solids (TSS) on fish eggs. *NIWA Client Report No:*, WLG2012-61: 21.

Partridge, G.J., Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper *Pagrus auratus.* . *Journal of Fish Biology*, 77 227-240. http://onlinelibrary.wiley.com/store/10.1111/j.1095-8649.2010.02679.x/asset/j.1095-8649.2010.02679.x.pdf?v=1&t=hs15kumb&s=8c0c061c91c3a63cbb561e9fc4726428dbf35770

Pinkerton, M. (2013) Ecosystem modelling of the Chatman Rise. *NIWA Client Report*: 157.

Rogers, B.A. (1969) Tolerance levels of four species of estuarine fishes to suspended mineral solids University of Rhode Island, Kingston.

Sherk, J.A., O'Connor, J.M., Neumann, D.A. (1975) Effects of suspended and deposited sediments on estuarine environments. In: L.E. Cronin (Ed). *Estuarine Research 2*. Academic Press, New York: 541-558.

Velterop, R. (2011) Galloper Wind Farm Project Environmental Statement – Chapter 13: Natural Fish and Shellfish Resources. *Royal Haskoning Reference 9V3083/R01/303730/Exet*: 148.

Westerberg, H., Rönnbäck, P., Frimansson, H. (1996) Effects of suspended sediments on cod eggs and larvae and on the behaviour of adult herring and cod. *ICES CM 1996/E:26*: 13.

Wilber, D.H., Clarke, D.G. (2001) Biological Effects of Suspended Sediments: A Review of Suspended Sediment Impacts on Fish and Shellfish with Relation to Dredging Activities in Estuaries. *North American Journal of Fisheries Management*, 21(4): 855-875. 10.1577/1548-8675(2001)021<0855:beossa>2.0.co;2

Wildish, D.J., Wilson, A.J., Akagi, H. (1977) Avoidance by herring of suspended sediment from dredge spoil dumping. , ICES Doc. C.M.1977/ E:11 (mimeo.).

6 Appendix

Appendix 1. Ocean Biogeographical Information System (OBIS) output of species sampled by research trawl in the CRP licence area 50270, searched April 2014.

Scientific name	Family	Common family	Common name	Benthic	Demersal or Pelagic
Alertichthys blacki	Congiopodidae	pigfishes	alert pigfish		y
Ambophthalmos angustus	Psychrolutidae	toadfishes	pale toadfish	y	
Argentina elongata	Argentinidae	silversides	silverside		y
Arnoglossus scapha	Bothidae	lefteyed flounder	megrim, witch	y	
Azygopus pinnifasciatus	Pleuronectidae	righteyed flounders	spotted flounder	y	
Bassanago bulbiceps	Congridae	conger eels	swollenhead conger	y	
Bassanago hirsutus	Congridae	conger eels	hariy conger	y	
Beryx splendens	Berycidae	alfonsinos	alfonsino		y
Brama australis	Bramidae	pomfrets	southern Ray's bream		y
Coelorinchus aspercephalus	Macrouridae	rattails, grenadiers	oblique banded rattail		y
Coelorinchus biclinozonalis	Macrouridae	rattails, grenadiers	two saddled rattail		y
Coelorinchus bollonsi	Macrouridae	rattails, grenadiers	Bollons' rattail		y
Coelorinchus fasciatus	Macrouridae	rattails, grenadiers	banded rattail		y
Coelorinchus oliverianus	Macrouridae	rattails, grenadiers	Oliver's rattail		y
Coelorinchus parvifasciatus	Macrouridae	rattails, grenadiers	small banded rattail		y
Centriscops humerosus	Macrorhamphosidae	snipefishes	redbanded bellowsfish		y
Centrolophus niger	Centrolophidae	raftfishes, medusafishes	rudderfish		y
Cyttus traversi	Zeidae	dories	lookdown dory		y
Cyttus novaezealandiae	Zeidae	dories	New Zealand dory		y
Deania calcea	Centrophoridae	dogfishes	shovelnose dogfish		y
Dipturus innominatus	Rajidae	skates	smooth skate	y	
Emmelichthys nitidus	Emmelichthyidae	bonnetmouths, rovers	redbait		y
Epigonus lenimen	Apogonidae	cardinalfishes	bigeye cardinalfish		y
Epigonus robustus	Apogonidae	cardinalfishes	Robust cardinal fish		y
Etmopterus baxteri	Etmopteridae	dogfishes	lantern shark		y
Etmopterus lucifer	Etmopteridae	dogfishes	lucifer dogfish		y
Galeorhinus galeus	Triakidae	hound sharlks	Tope shark	y	
Genypterus blacodes	Ophidiidae	cusk eels	ling	y	
Halaelurus dawsoni	Scyliorhinidae	cat sharks	Dawson's cat shark		y
Halargyreus johnsonii	Moridae	morid cods	slender cod		y
Harriotta raleighana	Rhinochimaeridae	longnosed chimaeras	longnosed chimaera	y	
Helicolenus spp.	Scorpaenidae	scorpionfishes	jock stewart	y	
Hoplichthys haswelli	Hoplichthyidae	ghostflatheads	deepsea flathead	y	
Hoplostethus mediterraneus	Trachichthyidae	roughies, slimeheads	silver roughy, sawbelly		y
Hydrolagus bemisi	Chimaeridae	chimaeras, ghost sharks	pale ghost shark	y	
Hydrolagus novaezealandiae	Chimaeridae	chimaeras, ghost sharks	dark ghost shark	y	
Icichthys australis	Centrolophidae	raftfishes, medusafishes	ragfish		y
Kathetostoma giganteum	Uranoscopidae	armourhead stargazers	giant stargazer, monkfish	y	

Scientific name	Family	Common family	Common name	Benthic	Demersal or Pelagic
Kuronezumia bubonis	Macrouridae	rattails, grenadiers	bulbous rattail		y
Lepidoperca aurantia	Serranidae	sea perches, gropers	orange perch		y
Lepidorhynchus denticulatus	Macrouridae	rattails, grenadiers	javelinfish		y
Macruronus novaezelandiae	Merlucciidae	Hakes	hoki		y
Merluccius australis	Merlucciidae	Hakes	hake		y
Micromesistius australis	Gadidae	true cods	southern blue whiting		y
Mora moro	Moridae	morid cods	ribaldo		y
Neocyttus rhomboidalis	Oreosomatidae	Oreos	spiky oreo		y
Neophrynichthys latus	Psychrolutidae	Toadfishes	dark toadfish	y	
Notacanthus sexspinis	Notacanthidae	spiny eels	spineback eel		y
Notophycis marginata	Moridae	morid cods	dwarf cod		y
Optonurus denticulatus	Macrouridae	rattails, grenadiers	thorntooth grenadier		y
Oxynotus bruniensis	Oxynotidae	rough sharks	prickly dogfish	y	
Pelotretis flavilatus	Pleuronectidae	righteyed flounders	lemon sole	y	
Photichthys argenteus	Photichthyidae	lighthouse fishes	lighthouse fish		y
Polyprion oxygeneios	Percichthyidae	temperate basses	hapuku, groper		y
Pseudophycis bachus	Moridae	morid cods	red cod		y
Schedophilus huttoni	Centrolophidae	Medusafishes	New Zealand ruffe		y
Seriolella caerulea	Centrolophidae	raftfishes, medusafishes	white warehou		y
Seriolella punctata	Centrolophidae	raftfishes, medusafishes	silver warehou		y
Squalus acanthias	Squalidae	dogfishes	spiny dogfish		y
Thyrsites atun	Gempylidae	Snake mackerel	snoek		y
Trachurus symmrtricus murphyi	Carangidae	jacks, trevallies, kingfishes	slender mackerel		y
Tubbia tasmanica	Centrolophidae	raftfishes, medusafishes	Tasmanian ruffe		y
Ventrifossa nigromaculata	Macrouridae	rattails, grenadiers	blackspot rattail		y