Possible impacts of marine farming of mussels (*Perna canaliculus*) on king shags (*Leucocarbo carunculatus*)

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CONTENTS

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ABSTRACT

The king shag (*Leucocarbo carunculatus*) is an endemic species classed as Vulnerable; its total population of c. 650 individuals is confined to the Marlborough Sounds, New Zealand. Possible effects of mussel farms are of increasing concern as some licence applications cover the deeper water favoured by the birds. The birds forage within c. 24 km from nest colonies and are deep divers, feeding on fish typically in areas with depths of 20–40 m; a flounder, witch (*Arnoglossus scapha*), was the main component of their diet. Mussel farms could have wide impacts on marine ecology, which may in turn affect king shags. Minor changes in current flows have been recorded, but more significant impacts are on bottom sediments and the water column through deposition of fine sediments (faeces and pseudofaeces) and shell litter in certain currents at a site. Currents and the amount of stratification at a site also determine how large an effect a farm has on the water column through removal of phytoplankton, inputs of nitrogen, and the creation of habitat for 'fouling' organisms. However, the flow-on effects of changes of the sediments and water column to the wider marine ecology, particularly the fish on which king shags depend, are poorly understood. Modelling research is examining cumulative effects of farms to estimate the carrying capacity of an area. There are risks of transferring unwanted organisms or diseases associated with farms. Proposals are made for monitoring the king shags and their diet and feeding ecology, and determining what impacts, negative or positive, mussel farms have on them.

Keywords: king shag, *Leucocarbo carunculatus*, Vulnerable species, mussel farms, environmental impacts, sediment deposition, sea currents.

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1. Introduction

The king shag (*Leucocarbo carunculatus*) is a rare endemic species confined to the Marlborough Sounds, New Zealand. Several mussel farms have been established in this region in recent years, and while they were confined to areas close inshore there was little concern about their possible impacts on the birds. However, there have recently been a series of applications to set up farms in areas of deeper water that overlap with the feeding areas of the birds. This report summarises current knowledge of the birds, reviews possible impacts of mussel farms on them, whether negative or positive, and identifies research needed to fill the gaps in current knowledge. It is hoped that this will assist the Department of Conservation and others to determine an appropriate response to farm applications and safeguard the future of this species.

It is worth noting that king shags are a species at the top of the marine food chain. If they are doing well, the marine ecosystem can perhaps be considered in good health, but if there are problems in the system they may be one of the first species to reflect this.

2. Taxonomy and conservation status of the king shag

2.1 TAXONOMY

The king shag is currently recognised as a full species, *L. carunculatus*, by the most recent New Zealand checklist (Turbot 1990), which is also adopted by the authoritative regional handbook (Marchant & Higgins 1990). However, it is clearly closely related to the Stewart Island shag (*L. chalconotus*) and Chatham Island shag (*L. onslowi*) with which it has at times shared sub-specific status (e.g. Fleming 1953). Worthy (1996) has shown that *L. carunculatus* and *L. chalconotus* cannot be distinguished on the basis of skeletal material, although there are some plumage differences (Marchant & Higgins 1990).

Melville (unpubl. 2001) recently reviewed the literature on the taxonomy of *Leucocarbo* shags in New Zealand. He recommended that, until a new 'authority' became available for reference it was most appropriate to retain the full species status for the king shag, based on Turbott (1990) and Marchant & Higgins (1990).

2.2 CONSERVATION STATUS

For the conservation management of the king shag, whether or not it is a full species is largely academic. It is clearly a distinct taxon, geographically separated from other related taxa and thus becomes a unit to be considered separately under international and national conservation criteria.

The IUCN Red List currently assigns the status of 'vulnerable' to the king shag (IUCN 2001), based on two criteria:

- population size estimated to number fewer than 1000 mature individuals;
- population with a very restricted area of occupancy (typically less than 20 km^2) or number of locations (typically five or fewer).

DOC ranked the king shag as category 'B', the second highest priority grouping for conservation (Molloy & Davis 1994). In a more recent classification it is ranked as Range Restricted (Hitchmough 2002).

3. Biology of king shags

It should be noted that the apparent close relationship between the king shag and Stewart Island shag does mean that observations on one species can be used to derive general predictions of the behaviour or ecology of the other.

3.1 CURRENT DISTRIBUTION

The king shag is currently confined to the Marlborough Sounds, where it has four main breeding colonies on offshore rock stacks or islands: at Duffers Reef, Trio Islands, Sentinel Rock, and White Rocks (Fig. 1). Two further small colonies exist. One is on Te Kuru Kuru (Stewart Island), which was occupied in the 1960s and which has recently had birds return, an average of 26 birds being present in late unpubl. 2001, with four nests built but apparently lost to storms (D. Boulton pers. comm.). The second is at a new site on the southern tip of Blumine Island, where up to 22 birds have been counted roosting since the first record in 1999 and the first nesting occurred in unpubl. 2001 with three nests, two producing a chick (W. Cash pers. comm.). These islands, together with a few other sites, are also used as roosts. Recent counts (Table 1) suggest a total population of about 650 birds, of which 600 are based at the colonies and 50 roost elsewhere (Schuckard unpubl. 2001). The colonies appear not all to be independent, Schuckard (unpubl. 2001) documenting an apparent shift of birds between Duffers Reef and the Trios in winter 1996.

Figure 1. Distribution of the king shag in the Marlborough Sounds. Results from bird mapping scheme.

3.2 POPULATION STUDIES

Full early morning counts of all the colonies within days of each other have only been undertaken since 1992. These suggest that the population has been stable over this period (Table 1). Earlier counts reviewed by Butler (1987) recorded lower totals of 333, 245, and 291 in the three years 1951, 1964, and 1987, respectively, in which all colonies were counted. However, these are considered significant underestimates as they were apparently done at times of day when many birds would have already been at sea, and at different seasons when some would have been away from the colonies.

There are indications of an increase in the number of colonies used. Early writers refer only to the White Rocks colony (e.g. Buller 1891) apparently discovered by H.H. Travers in 1875 (Medway 1987), and later (in 1896) to North

TABLE 1. BIRD COUNTS OF KING SHAG COLONIES IN THE MARLBOROUGH SOUNDS, 1948–2000.

COLONY	1992–2000[1]	1992[1,3]	1987[4]	1964[5]	1951[6]	1948–87[7]
Duffers Reef	204 ± 24[2]	168	68	85	150	75 (11–150)
N. Trios	205 ± 30[2]	165	93	30	95	57 (15–100)
Sentinel Rocks	55 ± 7[2]	68	78	20	18	20 (2– 78)
White Rocks	134 ± 12[2]	123	52	80	70	60 (20– 90)
Te Kuru Kuru	-	-	-	30	-	18 (5– 33)
TOTAL	592 ± 30[2]	524	291	245	333	230
Source	Schuckard 2001	Schuckard 1994	Butler 1987	Nelson 1971	Nelson 1971	Butler 1987

Notes: [1] The only counts conducted early in the morning before foraging birds had left the colony; [2] Count ± 1 SD; [3] Counts in Jun and Jul; [4] Counts in Apr except White Rocks in Aug; [5] Counts in Jul (2 colonies), Aug (1 colony), Nov (1 colony); [6] Counts in Mar (1 colony), May (1 colony), Sep (2 colonies); [7] Mean no. from all counts (and range).

Trio (Dawson & Dawson 1958). Colonies at Duffers Reef and Sentinel Rock were not recorded until 1951 (Nelson 1971) and a further small one was recorded on D'Urville Peninsula that same year which later shifted to Te Kuru Kuru Island and then ceased in 1965. Oliver (1955) records another colony at that time on the Chetwode Islands. The spread apparent by the 1950s could be evidence of an increasing population through this period, perhaps associated with the species being given legal protection, which occurred in 1924 (Nelson 1971). The recent use of Blumine Island and a return to Te Kuru Kuru could indicate a continuation of this trend.

Worthy (1996) has identified sub-fossil bones of a *Leucocarbo* shag in late Holocene dune deposits in Doubtless Bay, Northland, which are assigned to king shags as the geographically nearest birds. This is the first record of king shags in the North Island, although it is likely that other samples have been assigned to *Phalacrocorax carbo* in error. The sheltered harbours of Northland would have provided very similar habitat to the Marlborough Sounds. Worthy concluded (1996) that the distribution in the outer Sounds was a relict one and that the range contraction must have happened within the last 2000–3000 years. The most likely cause was being part of the diet, with other shag species, of the Maori, who first arrived c. 1000 years ago.

There appears to be no evidence of whether king shags were once distributed continuously between the Sounds and Northland or not. Any distribution would probably have been patchy, and limited by suitable feeding areas and colony sites. Evidence that the range was greater in the past does not necessarily mean that the population in the Sounds was any larger then, but it seems likely that any earlier colonies that were easily accessible would have been destroyed.

3.3 BREEDING BIOLOGY AND POPULATION DYNAMICS

Schuckard (1994) recognised a 6-month breeding season from courtship and the collection of nesting material in March through to the end of the fledging period in August. Nelson (1971) also identified a season of the same length but beginning in May, although rarely birds attempted two breeding cycles in a season when they started in March. She found that breeding was not completely synchronised across colonies, one going through a two-cycle season while the others had only one.

Table 2 summarises counts of nests at the different colonies. It shows that a relatively small number of birds appear to breed in any year, a minimum of 70 pairs and maximum of 166 in the years counted by Schuckard (unpubl. 2001).

TABLE 2. NEST COUNTS OF KING SHAG COLONIES IN THE MARLBOROUGH SOUNDS, 1948–2000.

COLONY	1992–2000 NESTS (FLEDGLINGS)	1992	1948–87
White Rocks	c. 26 (7–16)	30	14–40
North Trios	c. 30 (12–17)	50	6–55
Sentinel Rock	11–17 (1– 3)	17	2–18
Duffers Reef	30–34 (25–30)	69	20–80
Source	Schuckard 2001	Schuckard 1994	Butler 1987

Very little is known about the breeding biology except the clutch size which ranges from 1 to 3 eggs, with an average of 1.8 (n = 167) (Nelson 1971). It is possible that some gaps can be filled from a knowledge of closely related species.

3.4 FEEDING RANGE

King shags are solitary feeders who fly directly, low over the sea (or occasionally over narrow isthmuses of land). The range occupied by foraging birds has only been studied in any detail for the Duffers Reef colony (Schuckard 1994). He carried out observations in 1992 over 240 km of water defined from the flight directions of birds leaving the colony to feed, 75% of them heading in the S, SE, SW and W sectors. The average distance of foraging birds from the colony was 8.2 ± 4.1 km (± 1 SD, n = 219) and the maximum was 24 km (Fig. 2). There appeared to be no significant differences in the range between the breeding and non-breeding seasons.

Schuckard (unpubl. 2001) made two visits to assess the foraging range of birds at the Trios colony, in March and June 2001. On each occasion, over 80% of birds departed NW, W or SW, and foraging ranges were found to be similar to

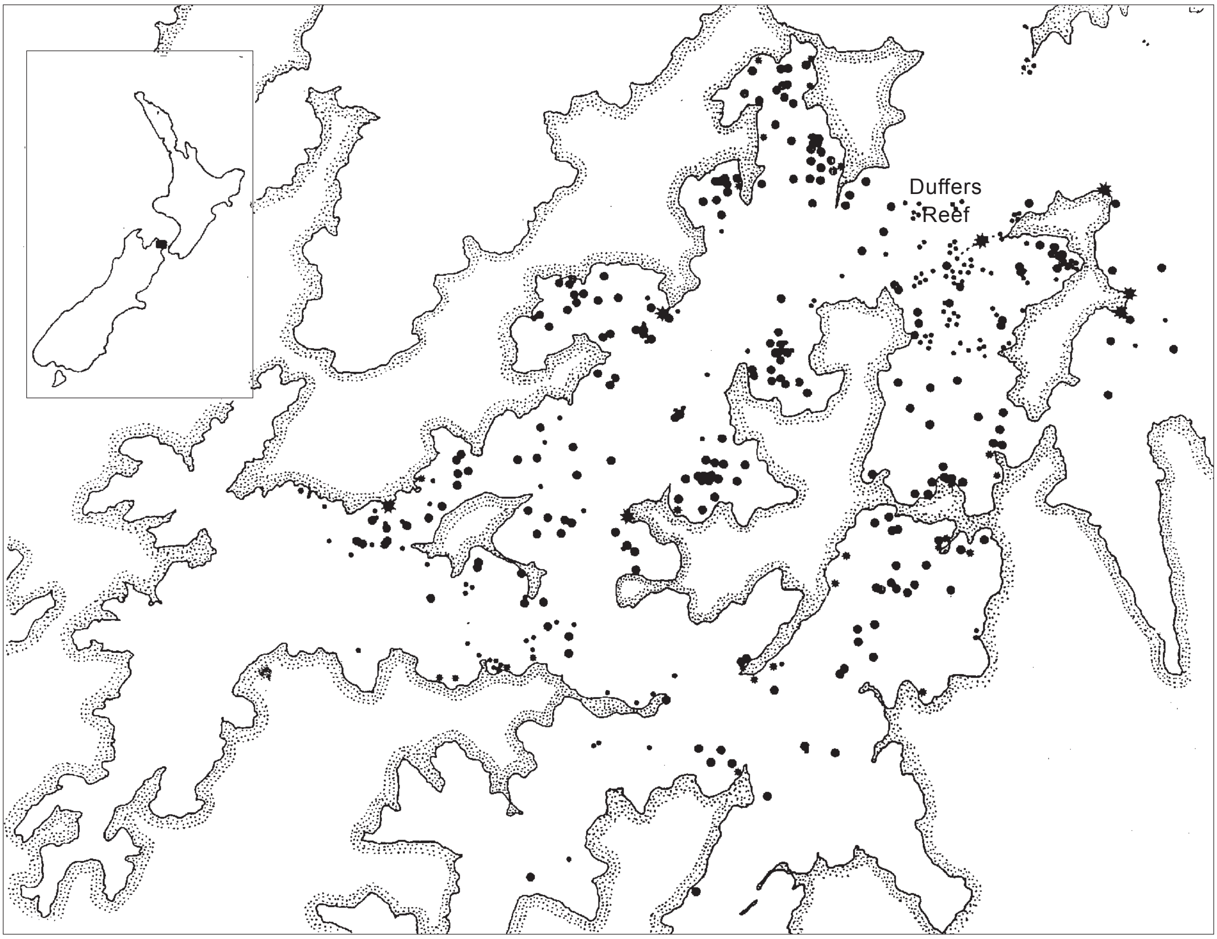

Figure 2. Foraging ranges of king shags from the Duffers Reef colony, Marlborough Sounds, 1992 (R. Schuckard unpubl. data used by kind permission). ✷ Birds seen at roosts or colony; ● birds seen on water during monthly trips; • birds seen on water during other trips.

those from Duffers Reef, averaging 9.0 ± 3.1 km (± 1 SD) with a maximum of 12.2 km (n = 12) although only a few birds were located.

Observations from the Marlborough Sounds Bird Mapping Scheme (Fig. 1) (Department of Conservation, unpubl. data) can be used to deduce a likely foraging range for birds from the White Rocks, given that they provide a similar picture to Schuckard's for Duffers Reef. They suggest a range c. 26 km long extending to the SW down Queen Charlotte Sound as far as around Ruakaka Bay. No reliable pictures can be deduced for the Sentinel Rock or the North Trio as the Scheme's observers were less active in the Outer Sounds; indeed, any foraging to the north of White Rocks is likely to have also gone undetected.

Schuckard (1974) recorded that 74% of the birds in Pelorus Sound were foraging in water between 20 and 40 m deep, though only 31% of the study area had water this deep. That ties in with the ecology of the *Leucocarbo* shags, which are considered to be dive deeper than other shag species. This finding, together with the foraging range described, has been used to define the likely areas of overlap with marine farms. Most marine farms to date have been within 200 m from the shore, bordering on or partly overlapping with the depth range favoured by king shags. Recent applications have extended further offshore and thus fully overlap with it. At 20–40 m depth the sea floor is mainly flat (63%, according to Schuckard (unpubl. 2001)) and characterised by fine muddy sediments.

Schuckard (unpubl. 2001) reviewed the feeding ecology of a range of shag species. Key findings were that colonies were generally located downwind from feeding areas so that birds returning with food were typically assisted by a tailwind. Shags generally have high energy requirements as they are some of the heaviest birds to rely on flapping flight. King shags being among the heaviest and the deeper divers are very likely to exemplify this. Foraging patterns of shags are most strongly influenced by prey availability and feeding ranges similar in size to those described for the king shag are found in a range of species.

The characteristics of the king shags' foraging range remains one of the key questions. Davidson et al. (1995) mapped feeding zones for the king shag in Pelorus Sound as areas in which there had been three or more observations of foraging birds within 1 km of each other. Some marine farm applicants have then assessed the degree of overlap between their farms and these zones as a measure of likely impacts on king shags. Others have collected additional observations of their proposed location, such as the study of Brown (unpubl. 2001). He made four visits to Forsyth Bay in January–March 2000 and observed no foraging shags in the farm application site. Of 13 foraging observations in the wider bay, six were within 100 m of the site, and these, if grouped as done by Davidson et al. (1995) would give a 'feeding zone' overlapping the western section of the proposed farm. Such site-specific observations have been considered useful, as Brown (2001 cited in Melville unpubl. 2001) has described feeding areas as reasonably discrete and somewhat localised. This implied that the shags had more specific feeding habitat requirements than depth alone.

Whether the feeding range identified in Schuckard's (1994) 'snapshot' of Pelorus Sound can be used as definitive, and therefore whether the feeding zones of Davidson et al. (1995) have validity over the long term, has quite appropriately been questioned (e.g. by Lalas (unpubl. 2001)).

Another key question is whether the distance of a feeding area from the colony is significant. Several scenarios are possible, or perhaps a combination of them. Birds might select a foraging area at random from within the described feeding range, although they would be unlikely to fly further than necessary to obtain a feed. Alternatively, sites nearer the colony might be monopolised by certain individuals, forcing others to fly further. Breeding birds may forage differently from sub-adults, or this could vary with stages of the breeding cycle. Sites nearer the colony could have greater value, as birds would have to expend less energy flying there and back so there would be a greater net gain from the catch. It would be useful to know where the relatively small percentage of birds that are productive breeders feed, although this could not be answered without marked individuals.

An area up to 2 km from Duffers Reef was seen to have a wider use than just feeding (Schuckard unpubl. 2001). Juveniles were seen to take their first swims here and adults tended to bathe close to the colony before flying off to feed.

3.5 DIET

In general, the *Leucocarbo* shags feed mainly on bottom-feeding fish caught by deep diving. One detailed study of the king shag diet has been carried out using pellets obtained from a roost in Pelorus Sound c. 10 km from the Duffers Reef breeding colony (Lalas & Brown 1998). It has been considered that this provides a good indication of the likely diet of the birds using that colony. However, anecdotal records from samples obtained in other parts of the Sounds show fish not recorded in the Pelorus study, so the information cannot necessarily be applied to the species over the whole of its range.

Lalas & Brown (1998) examined 22 freshly regurgitated pellets from the Te Kaingapipi roost (Pelorus Sound), 12 collected when birds were not breeding in November 1991 and 10 in the breeding season in May 1992. Such pellets are considered to be produced daily and the sample thus provides a good indication of the range of hard-bodied species (detected as otoliths or other skeletal parts) eaten daily by the birds using the site, typically less than five (range 0–22 birds seen there).

There was little seasonal variation observed, although May samples had slightly fewer items and less of the flounder, witch (*Arnoglossus scapha*), so the two seasons were combined. Overall, witch was the dominant prey item, being found in all pellets, making up 90% of the detected food items and an estimated 95% of wet mass. Other items of some significance were opalfish (*Hemerocoetes* sp.) (4–7% of items), and righteyed flounders (lemon sole (*Pelotretis flavilatus*), other sole species (*Peltorhamphus* sp.) and flounder, *Rhombosolea* sp.)) which totalled 1–2% of items. Crustacea were insignificant and those found may have originated from within the fish caught. Most of the witch were of an estimated size range averaging 10.8 (November) to 14.8 cm long (May), and were considered to represent the same cohort of juvenile (first-year) fish.

Lalas & Brown also collected four pellets from the Trio Islands in March 1992 (Lalas unpubl. 2001) which yielded > 20 prey items, of which only 4 (20%) were witch. Other species found were leatherjacket (*Parika scaber*) (7), blue cod (*Parapercis colias*) (3) and sea perch (*Helicolenus percoides*) (2).

Previous incidental records of king shag diet include blue cod, red cod (*Pseudophycis bachus*), red scorpionfish (*Scorpaena papillosus*), pilchard (*Sardinops neopilchardus*), common sole (*Peltoramphus novaeseelandiae*), sandfish (*Gonorhynchus gonorhynchus*), and lobsters and crabs but no witch (Lalas & Brown 1998).

The study suggests that it may be appropriate to concentrate on witch when considering any possible impacts of marine farms on the food supply of king shags based at Duffers Reef in Pelorus Sound, but this cannot be extrapolated to other sites. Even extending the results from birds roosting away from Duffers Reef to those breeding at the colony could be risky. Further caution in interpreting these results is suggested by findings from Cape cormorants (*Phalacrocorax capensis*) that daily, monthly and regional variation in the diet can be three to four times that of annual variation (Schuckard unpubl. 2001).

4. Ecology of prey of king shags

Witch, a left-eye flounder (Bothidae), is the most abundant flounder in New Zealand. It is found in shallow to deep water (over 400 m) around both islands and feeds mainly on worms, crustacea and molluscs and occasionally small fish (Ayling & Cox 1982). Spawning occurs from August to April around the South Island and southern tip of the North Island.

Livingstone (1987) conducted a detailed study of the annual diets of five species of flatfish in Wellington Harbour from gut contents. She found considerable differences between witch and four right-eye flounders (Pleuronectidae - NZ sole, lemon sole, sand flounder, and yellow-belly flounder) in both diet and gut morphology. The diet of witch consisted almost equally of small fish and shrimps, whereas the other species took mostly ophiuroids (brittle stars), crustacea and infaunal or epifaunal polychaete worms. The main prey items of witch were pelagic, active mid-water prey (*Periclimenes yaldwyni* and *Engraulis australis*) and they were classified as visual feeders, whereas for the other fish the main items were infauna or epifauna and most were non-visual feeders. The study found the witch to be most common in deeper water with coarse grained sediments, whereas the other species were in areas underlain by fine sediments. Generally the right-eye flounders are not found as deep as witch, favouring a depth range of 50–100 m (Cox & Ayling 1982; Ayling & Cox 1982).

However, regional differences suggest diets vary with the potential items available. Witch have been reported feeding on polychaetes and ophiuroids, and some of the other species on fish and other active prey. Water clarity/turbidity was considered a major factor behind local variation.

5. Threats to king shags

The following possible threats to king shags have been identified:

- Human disturbance at breeding colonies. Nesting birds are very susceptible to disturbance by boats and low-flying aircraft (fixed-wing and helicopters) and may abandon eggs or chicks, which can be lost due to chilling or predation by gulls.
- Set-netting, line fishing, crayfish pots. All these have been known to kill shags elsewhere, and several nets have been observed next to the Te Kuru Kuru site recently (D. Boulton pers. comm.).
- Shooting. Shooting of shags because they are considered competitors of fishers or fish farms is known, and king shags could be affected.
- Oil spills.
- Marine farms. Stattersfield & Clapper (2000, cited in Melville unpubl. 2001) recommended the prevention of marine farming close to colonies and feeding areas.

- Failure of food supply, e.g. failure of witch production if juveniles are a key food.
- Predation at colonies. Rats have been caught in the past on Duffers Reef islets adjacent to the colony. They were removed by trapping and poison stations are maintained to prevent a recurrence. The possibility of the accidental introduction of rats to this and other sites remains, e.g. following a shipwreck.
- Climate change. Lalas (unpubl. 2001) noted that the king shag is the most northerly of the *Leucocarbo* shags and he considered that the small population size might be related to the climate. In summer, birds on the colonies are observed panting, which may indicate heat stress. If this is the case, global warming might threaten the population.
- Disease.
- Stochastic (random) events can cause problems when numbers are very low. An example might be a strongly biased sex ratio among the chicks produced one year which could lead to a shortage of one sex of adults and in turn to reduced productivity.

6. Potential effects of marine mussel farms

A typical 3 ha mussel farm contains up to 10 longlines on each of which are 30–40 large floats which support two backbones 110 m long. From the backbones the mussels are grown on a continuous rope 2500–3000 m long which is suspended in a series of loops (droppers) 5–10 m in length (Jeffs et al. 1999). Each longline is anchored at both ends to the seabed by 4–8 tonne concrete blocks or screw anchors. The spacing of the longlines and thus the intensity of the operation varies from farm to farm.

The larger farms (c. 40 ha) of recent applications are typified by one for Orchard Bay (Mitchell unpubl. 2001). The longlines are 170 m long with 90 m anchor warps at each end, and seven of them are at 49 m spacing in a block, of which four are separated by a 125 m ‘fairway’ (Stage 1). Grow lines drop for 15 m.

An overview of ecological effects from mussel farms in the Marlborough Sounds has been provided by Forrest (1995).

6.1 PHYSICAL EFFECTS OF MARINE FARMS

6.1.1 Structures

Most of the farms in the Marlborough Sounds cover areas of 3–5 ha. However, more recent applications have included those for larger farms in deeper water. Examples include a farm measuring 650 × 650 m (including backbones and anchor warps covering 42 hectares) in Forsyth Bay and one of 700 × 700 m covering 49 ha in Orchard Bay.

The structures could have several impacts on king shags. The rope system could impede diving and the pursuit of prey and possibly cause injury to birds. However, there is no evidence that this is a problem, the ropes being coarse and very visible, and birds have been observed feeding within farms on occasions (Brown unpubl. 2001; Lalas unpubl. 2001).

King shags have been observed perched on the floats but do not apparently roost on them overnight like spotted shags will (Lalas unpubl. 2001). Brown (unpubl. 2001) observed 38 king shags roosting on mussel floats and only four on land within a study area, suggesting the floats might be favoured. Shags tolerated much closer approaches by boat when sitting on the floats than when on land, which Brown considered to be due to the extra security they felt from having water on all sides. He made fairly frequent observations of birds exiting the water directly on to buoys and two of them initiating dives directly from buoys.

It should also be noted that many of the more established marine farms have been relatively close inshore. Any problems relating to farm structures may become apparent as farms move into deeper water where more shag feeding occurs.

6.1.2 Lights

All farms have some form of lighting to ensure they pose no threat to navigation, and some have sufficient to allow some operations to be carried out at night. However, shags roost ashore at night so will not be affected and indeed Stewart Island shags have nested on a navigation beacon platform in Otago Harbour (Lalas unpubl. 2001).

6.1.3 Structural debris/litter

There have been problems in the Sounds with ‘sacrificial’ rope ties from mussel farms discarded in the sea and then picked up by gannets (*Sula serrator*) for use as nesting material. Adults and chicks have become entangled in this. There is not any evidence of this occurring with shags. Plastic litter could create similar problems.

6.1.4 Shell waste

Currently shell waste is dumped in landfills, although there have been suggestions of returning it to the sea. The possible impacts of this on king shags might be a matter for future assessment.

6.2 EFFECTS OF ACTIVITIES ASSOCIATED WITH MARINE FARMING

6.2.1 Disturbance by boats

It is well established that king shags are vulnerable to disturbance by boats approaching too close to colonies while they are nesting, and this has led DOC to propose marine buffer zones around them, 1000 m in width (Davidson et al. 1995). They also propose zones of 500 m around roosting sites and list two of these, Te Kaiangapipi and Boat Rock Point in Pelorus Sound. These zones are used for controlling activities such as marine farming that might be proposed within them.

Lalas (unpubl. 2001) describes recent investigations he has made of the possible disruption of birds' feeding through the approach of boats. He studied king shags in Pelorus Sound (Lalas unpubl. 2000) and made comparisons with observations of Stewart Island shags in Otago Harbour and spotted shags and little shags at both locations. King shags and Stewart Island shags showed similar behaviour, being the least tolerant of the species to approaches on the water and most tolerant while resting onshore or on emergent objects. They would both cease foraging when approached to within 200–300 m and would escape, by diving, at distances of 50–100 m.

For the Pelorus study in May 2000, he approached birds of four species on the water at two speeds, 10 km/h (5 knots) and 50 km/h and recorded 'reaction distances' (maximum distances at which birds exhibit a tangible response to the boat's approach) and 'escape distances' (distances at which birds dived or flew away). At 10 km/h the average reaction distance of king shags was 132 m (max. 229 m, $n = 25$) and at 50 km/h it was 185 m (max. 261 m, $n = 25$). These distances were much longer than those observed for spotted shags (averages of 72 and 120 m for the two speeds, respectively) and pied shags (65 and 107 m) but shorter than that of little shags (176 m at 10 km/h). Escape distances for king shags, 43 m (max. 95 m, $n = 25$) at 10 km/h and 87 m (max. 183 m, $n = 25$) at 50 km/h, were similar to the distances for spotted shags (averages of 43 and 69 m for the two speeds) and pied shags (43 and 84 m) but significantly shorter than for little shags (172 m at 10 km/h).

On 49 of the 50 occasions, king shags 'escaped' by diving. The estimated period of disruption to foraging was 90 sec (max. 180 sec) at 10 km/h and 30 sec (max. 42 sec) at 50 km/h. More spotted shags escaped by flying as did most pied shags and all little shags, so foraging bouts of king shags were interrupted significantly less than those of the other species. It also meant that king shags resumed foraging around their original chosen location.

The trials of disturbing resting birds found that king shags reacted at an average 36 m ($n = 6$) at 10 km/h and 30 m ($n = 6$) at 50 km/h and escaped at an average 30 m at 10 km/h and 31m at 50 km/h. These results were similar to those of spotted shags, but little shags and pied shags were generally more 'flighty'.

These results suggested that the passing of boats had less impact on king shags than some other species and was unlikely to have a significant impact on their foraging and resting activities. The establishment and subsequent growth of the Stewart Island shag colony in Otago Harbour despite regular boat traffic was considered evidence by Lalas (unpubl. 2001) that this was not a significant detrimental factor to shag populations.

6.2.2 Noise

The noise of boats, mussel harvesters, and other machinery associated with marine farms is considered unlikely to pose a problem to foraging king shags. Brown (unpubl. 2001) reports a king shag fishing beside a farm and returning to rest there despite a mussel boat noisily lifting lines c. 60 m away. However, significant noise near breeding colonies, that differed from the passing boat traffic that birds might be used to, could be a problem. Siting farms at sufficient distance from colonies is the obvious way to address this problem.

6.2.3 Water pollution

Mussel farming itself does not make use of chemicals on site. However, boats are potential sources of fuel oil or wastewater through accidental discharges, and a significant risk could exist in the event of a damaging collision between a larger boat and a farm. However, there are strict requirements for marking and lighting farms and observations of collisions suggest that they are unlikely to result in damage of a nature that would cause a spill as the farm presents a very flexible structure that absorbs the impact.

6.3 EFFECTS OF MARINE FARMS ON MARINE ECOLOGY

The introduction of marine farm structures can affect local hydrography and provides new substrates for epibiota to settle and grow. The introduction of high densities of cultivated organisms increases the local demand for oxygen, removes phytoplankton and elevates the input of organic matter into the immediate environment (Kaiser et al. 1998).

6.3.1 Hydrography changes

Farm structures can lead to complex changes in current flows, their degree varying with the orientation of the longlines to the direction of the prevailing current (James unpubl. 2001). However, these changes will typically be localised to the immediate vicinity of the farm.

6.3.2 Sediment changes

Farms generate two types of 'sediment'. Firstly, faeces and pseudofaeces (mucous-bound particles expelled without passing through the gut) from the mussels and other organisms growing on the mussel lines fall as organic-rich, fine-grained particles. The farm is in effect acting as a filter, forming fast-sedimenting pellets from planktonic particles (Gillespie unpubl. 2001). Secondly, there is also deposition of live mussels, mussel shell litter, and the remains of other associated biota below a farm.

Mussel farms in the Sounds are typically located over mud habitats. At the depths associated with recent proposals (30–40 m) these deep mud habitats typically contain a diverse biota of 70–110 species over a large area (> 40 ha) (Gillespie unpubl. 2001). The epifauna (surface-dwelling) of Forsyth Bay is dominated by heart urchins and brittle stars along with tubeworms, bivalves and crustacea. A similar area in Admiralty Bay, studied by Forrest & Barter (1999, cited in Inglis unpubl. 2001), had > 30 taxa, with heart urchins and brittle stars again the most common. Assessing possible changes to this biota following the deposition of fine sediments and shell drop is critical to determining possible flow-on effects up the food chain through fish to king shags.

A relatively large number of detailed studies of fine sediment deposition have been carried out. A range of responses of the sea-floor biota have been identified, from little or no community modification after low levels of nutrient enrichment, through to major alterations and the dominance of small polychaetes and absence of larger animals such as molluscs and urchins after high levels (Gillespie unpubl. 2001). Substrates at this end of the scale are high in sulphides and low in oxygen.

Fine particle sedimentation below mussel farms was over twice that of surrounding areas, 2.4 times in a Canadian example (Grant et al. 1995) and 2–13 times at Beatrix Bay (Inglis unpubl. 2001), the higher figures there arising during storms and harvesting. Studies by the Cawthron Institute have documented the zones under farms affected by sediment deposition (Gillespie unpubl. 2001); 80% of fine particles fell within 174 m of the edge of the farm's shadow in Forsyth Bay. Applying this more widely, assuming similar currents, would mean that a 9 ha farm would affect 22 ha of seabed and a 42 ha farm would affect 67.5 ha of seabed.

Significant changes in biota following deposition have been recorded by Kaspar et al. (1985) in Kenepuru Sound, a site with low current; the benthic fauna under a 5 ha zone influenced by a farm consisted largely of polychaete worms whereas the reference site contained in addition bivalves, brittle stars and crustacea. Detailed studies under a small farm in 7 m of water in Nova Scotia showed the reference site to have a greater average number of individuals of major faunal taxa all seasons (Grant et al. 1995); however, gastropods and scavenging species were always more numerous under the farm so that at times this area had the greater biomass. No obvious negative changes had occurred over a 10-year period except a partial shift towards anaerobic conditions.

The extent of any sediment effect varies in particular with the currents at a site. Kaiser et al. (1998) quote a Spanish example (Rodhouse & Roden 1987) of a site well flushed by tidal currents in which deposits did not accumulate and there was a 'favourable' increase in macrofaunal biomass under the farm. However, in a Swedish example (Dahlback & Gunnarsson 1981) with deposition about twice that away from the farm (2.4–3.1 g organic carbon/m^2/day) excessive organic enrichment led to an anoxic sediment covered in bacterial mats and low diversity and biomass of benthic infauna. Different impacts of two farms close to each other but subject to different current conditions were shown by Chamberlain et al. (2001). One was an 8-year-old 100 t/yr farm, which had residual current velocities around twice those of a similar farm (c. 14 years old 150 t/yr) in an adjacent bay (1.25 v. 0.76 cm/s at upper levels and 0.75 v. 0.40 cm/s at lower levels). No alterations in the benthic communities were recorded under the first, whereas the second showed evidence of organic enrichment and reduced faunal diversity.

'Shell drop', the deposition of shells, live mussels and associated biota, largely affects the area directly below the farm, typically to 20 m from its boundaries (Inglis unpubl. 2001). The value of shell drop in creating a reef-like substrate seems very variable; under some farms the litter is barren, whereas under others there can be a rich biota, including sponges, ascidians, anemones, tube worms together with starfish, sea cucumbers and crabs (Gillespie unpubl. 2001). Inglis (unpubl. 2001) notes that studies have predicted increases in: encrusting fauna, anemones and sponges; mobile invertebrates and fish which use the material for shelter; predators such as sea stars; and scavengers like hermit crabs. Differences in current will be responsible for much of the variability. In high-current areas, fine sediments will largely be swept away leaving the shell 'clean'. However, the stability of the resultant 'reef community' is questionable, given the constant rain of shell from above (Baxter, A. pers. comm.).

6.3.3 Effects on water column

The inshore water column is inhabited by planktonic algae, zooplankton and dispersive planktonic phases of other species (e.g. fish), and productivity there is limited by light and nutrients, particularly nitrogen (James unpubl. 2001). The column is frequently stratified due to the separation of water layers with different densities associated with changes in salinity or temperature. Inner Pelorus Sound, for example, often shows salinity stratification in winter (as a result of freshwater inputs) and temperature stratification in summer (due to surface heating). The Outer Sounds, which have less freshwater input, tend to show weaker stratification. The amount of stratification will be important in determining the effects of a marine farm at a site, particularly through its effects on phytoplankton, which may sometimes be held in higher layer while nutrients may be concentrated at lower levels.

The impacts of a farm can be considered in terms of nitrogen alone, which can at times be at such low levels as to limit plankton growth (as in Beatrix Bay studies). The harvesting of mussels will periodically remove nitrogen from the aquatic system. Kaspar et al. (1985) calculated that, based on an average turnover of mussels of two years, denitrification was 68% higher at the farm study site compared to a nearby reference site. Further research is in progress on the role of nitrogen in limiting phytoplankton growth and thus in turn mussel growth (Ogilvie 2000). A positive response was seen from adding nitrogen to the water in summer. 'Fertilising' the sea in this way could become a management practice and flow-on effects on zooplankton and fish and king shags would need assessment.

Phytoplankton is a key element in the marine food chain, providing food for mussels as well as for zooplankton and some fish. Depletion of phytoplankton by mussel farms has been measured in detail in Beatrix Bay (Gall et al. 2000). Strong seasonal patterns were observed over five years, with the summer months (Nov–Feb) showing lowest phytoplankton biomass associated with low concentrations of nitrates and ammonia and stratification of the water column, and winter showing the highest, particularly during a late-winter/spring bloom of diatoms. However, winter biomass was reduced if there was weak water stratification and many phytoplankton were carried deeper where there was less light. Maximum depletion rates found in May were 72%, 44% and 18% in inner, mid- and outer-bay farms, respectively (James unpubl. 2001). In summer, phytoplankton levels were elevated within farms in response to ammonia excreted by the mussels at a time of very low natural levels of nitrogen.

The area of water in which phytoplankton depletion occurs is clearly important in determining the impacts of a farm. At one of the largest complexes in the region, where farms cover an area of 80 ha in Golden Bay, phytoplankton levels recovered to within ambient concentrations within 200–500 m of the farm boundary. Water circulation and movement determine the distribution of phytoplankton and rates of replenishment with new water and nutrients, so the location of this farm in the open sea will have tended to reduce any impact. A proposal for the staged development of a farm at Forsyth Bay suggests a requirement that densities of mussel lines be such that depletion rates are not detectable 500 m from the farm boundary (James unpubl. 2001).

6.3.4 Creation of new habitat

The mussel lines can be considered to be new temporary habitats created in the water column for a range of animals in addition to mussels. The epifaunal community on mussels has been recorded to consist of over 100 different species (Tenore & Gonzales 1975, cited in Kaiser et al. 1998). The ammonia excreted by the mussels can lead in particular to very high productivity of seaweeds attached to the lines (Kaiser et al. 1998).

6.3.5 Other effects

Farms exclude trawlers from areas, and this has resulted in enhanced numbers of scallops and horse mussels at sites (Inglis unpubl. 2001). They also cause some shading of the seabed which may reduce the light available to phytoplankton or algae.

6.3.6 Flow-on effects

There is debate about the extent to which the mussel lines and their attached animals and plants attract fish and thus provide increased food for certain species. Farms are placed over muddy habitats which are not favoured by species like snapper and blue cod but tend to support dogfish, opalfish, juvenile flatfish, and red gurnard (Inglis unpubl. 2001). Snapper and kingfish may be attracted during harvesting. A spokesman for recreational fishers in the Sounds has suggested that fishing is generally not good around farm structures (Williams unpubl. 2000). They may cause aggregations during seeding out and harvesting but generally only of snapper and leatherjackets and he did not consider that these caused an overall increase in fish numbers.

The more significant effects could occur as a result of the changes to the sediments and water column. One suggestion relating to the former is that increased food below farms could allow predators (e.g. starfish) to build up to some critical level for spawning at which a population response might occur. This increase in recruitment locally could then have predation effects some distance away from the site (Inglis unpubl. 2001).

Grant (1996) reviewed the possible effects of bivalve farming on energy flows in the water column at the ecosystem level. Some modelling studies suggested that zooplankton populations and some benthic species may be out-competed by the farmed bivalves. Whether depletion of zooplankton as well as of phytoplankton could reach a critical level for fish is uncertain, particularly given the complexity of trophic interactions between fish, zooplankton of different sizes and the bivalves. The last may for example be ingesting the smaller zooplankton which would otherwise compete with larger zooplankton and juvenile herbivorous fish for phytoplankton food.

There have been few studies of zooplankton of the Marlborough Sounds. However, the zooplankton communities found in Pelorus Sound and Cook Strait have been shown to be diverse, with a relatively constant biomass through the year and omnivores the dominant taxa (Inglis unpubl. 2001). The Beatrix Bay study included an assessment of the influence of meso-zooplankton (animals 20–200 mm long) on phytoplankton (Davis 2000), which showed that the interaction was a complex one, not the simple model of the meso-zooplankton having a direct effect on numbers of the phytoplankton through predation.

While the flow-on effects of any given farm will be difficult to predict because of the complex biological interactions involved, a more critical issue will be what the combined effects of several farms sited close together have on wider marine ecology. One approach has focused on phytoplankton, seeking to ensure that the total biomass extracted in a region is much less than the re-supply of phytoplankton. Detailed studies at Forsyth Bay have estimated that the maximum volume of water filtered by a farm is 6% of the incoming water for the region and that the average farm can extract about 9.3% of phytoplankton available (Hayden et al. 2000).

It has been suggested that thresholds based on mussel carrying capacity provide the best estimates for ecological carrying capacity of the water column. After six years of work at Beatrix Bay, the National Institute of Water & Atmospheric Research has established a carrying capacity model that suggests that the present stocking level of 2500 tonnes of mussels could be increased to 6000 tonnes without losses in productivity (Hayden et al. 2000). However, they emphasise that this model cannot not reliably be applied to other sites without further work.

6.3.7 Unwanted organisms, disease and algal blooms

Mussel farms can act as reservoirs for the incubation and spread of nuisance organisms such as the seaweed *Undaria,* which is now found in the Sounds, although, in this case, when it is dislodged during farm maintenance it cannot re-establish itself on the muddy bottom (Inglis unpubl. 2001).

The seeding of farms with spat is a possible route for the transfer of unwanted organisms. Until recently c. 80% of the spat was obtained from Ninety Mile Beach, where it can wash up in large quantities on seaweed. This spat-covered seaweed is then transferred to the Sounds where it is held on the dropper lines with biodegradable stockings (Jeffs et al. 1999). The fouling of boat hulls, buoys or ropes are other possible routes.

There are inherent risks in any farming that involves a monoculture with large numbers of an organism grown at high densities. There appears to be no evidence that this has increased the presence of any diseases that could spread to wild populations or other species. Studies have been undertaken to understand whether mussel farming might induce some organisms to produce toxins and new shellfish poisoning species were found in local mussel farms in the Adriatic (Cabrini unpubl. 2001); however, a link between the two is apparently not yet established.

7. Spat catching

The potential impacts of spat catching have not been considered in detail as this activity is not currently carried out to a significant extent in the Marlborough Sounds. However, the fibrous rope structures involved (held at 15–20 m depth) cover more of the water column than mussel farms and may obstruct feeding activity of shags, pose a greater risk of entanglement, and apparently generate more debris. An increase of spat catching to the Sounds might thus require separate assessment.

8. Research needs and proposed strategy

8.1 INFORMATION GAPS

The following research needs have been identified for the king shag from Taylor (2000) and from a workshop held at DOC, Nelson, on 28 August 200.

1. Population status and dynamics. To provide accurate censuses of the population and data on age of first breeding, longevity, adult mortality, chick survival & recruitment, etc. It is suggested that this work could be done first with Stewart Island or Auckland Island shags, although a banding study of king shag chicks could be attempted
2. Breeding biology. To provide more detailed data on breeding season, laying dates, clutch size, chick growth rates, etc.
3. Limiting factors. What are the factors that limit the apparent inability of the population to increase above current levels?
4. Taxonomy.
5. Annual and geographic variations in diet.
6. Feeding behaviour. Specifically, do king shags select certain prey or feed in proportion to availability?
7. Feeding range for all colonies.
8. Use made of existing mussel farms by king shags.

9. Flow-on effects of farms on marine biota, particularly fish.

10. Carrying capacity of an area for farms before negative flow-on effects occur.

All of these except the fourth have some relevance to the question of identifying the impacts that mussel farms may have on the species.

Any changes observed in the king shag population cannot in themselves be related to mussel farming. However, if a decline became apparent, the precautionary principle would mean that, until more about the impacts of farms was known, further farms in areas that overlap with the activity range of the birds should be discouraged.

8.2 SUGGESTED RESEARCH PROJECTS

Project 1: Population census of king shag

Objective: To obtain accurate annual estimates of the breeding population.

Counts to be conducted at all the breeding colonies at first light at the same time of year (as Schuckard 1994). Ideally, several counts should be conducted at each site over several days to give some precision to the population estimates obtained. An alternative would be to do the sequence of daily counts at only one of the colonies (e.g. Duffers Reef)—if the daily variation was found to be small, single counts each year should be adequate.

Resources required: One or two observers and a boat for eight days—a day at each major colony plus assessment of Blumine Island on return from White Rocks and four days for consecutive counts of Duffers Reef.

Project 2: Population dynamics and breeding biology of king shag

Objectives: To describe some of the key parameters affecting shag numbers, e.g. productivity and mortality, with an emphasis on understanding any factors that may limit the population.

So little information is known that this requires significant effort. It has been suggested that work is undertaken first on more common *Leucocarbo* shags such as the Stewart Island shag (Nelson 1971), both to provide estimates of key parameters that might equally apply to king shags and to develop techniques that could be applied. In particular it will not be possible to obtain some information without individually marked birds, and techniques of capture and marking need development.

Resources required: A major research project would be needed on a related species over several seasons, perhaps suitable for a PhD. A similar effort would then be needed to be applied to king shags themselves. It would not seem to be the responsibility of the marine farming industry to support such basic research and it needs further discussion within the Department.

Project 3: Diet of king shag

Objective: To describe the annual diet of the king shag over all foraging areas.

Regurgitated pellets need to be collected from all four of the major breeding colonies. Lalas & Brown (1998) have suggested that 10 fresh, complete pellets per site would be sufficient if prey composition was as uniform as in their study and recorded that it took an average of five hours to analyse one. However, more variation from pellet to pellet and season to season could be expected, particularly perhaps in the Outer Sounds, so at least 20 pellets might be needed per colony from each of two seasons (breeding and non-breeding). It is suggested that attempts be made to collect this number of pellets and that half of them are then analysed to determine the variation and decide if the other half is needed.

Resources required: Minimum of two people plus boat for two days (Pelorus/ Outer Islands, Queen Charlotte Sound).

Time needed: 400 hours for pellet analyses; 24 hours to write up; additional 100–400 hours to analyse further pellets to obtain diet description with acceptable variation.

Project 4: Feeding range and behaviour of king shag

Objective: To define the feeding ranges of birds from all breeding colonies and assess the daily and seasonal variation in its use.

The study of Schuckard (1994) should be repeated for the colonies at the Trios, Sentinel Rock, and White Rocks to determine the approximate feeding ranges of birds from these. This would again involve identification of the range of departure directions from the colonies, then recording the positions of foraging birds. Then some more intensive work is needed in Pelorus Sound to assess how fixed the feeding range described by Schuckard is and determine whether birds selected certain areas or fed largely at random within a certain depth range. The precise pattern of use of certain bays by feeding shags needs to be documented over periods of consecutive days at several different times of year. In addition to location of feeding dives, their times and any prey brought to the surface should be recorded. Bays close to the colony, e.g. Forsyth, and ones further away such as Richmond or Waitata Bay could be used.

This foraging work could be extended through the use of individually recognisable birds, e.g. marked with patagial (wing) tags. This would allow identification of the feeding ranges of individuals, and if the sample was sufficient, of whether the ranges of the relatively few productive birds differed from the others. Such research would have to follow work under Project 2.

Resources required: Discussion is needed with Schuckard to determine how much effort he put into his Pelorus study. He was able to define feeding sites for 12 shags during two visits to the Trios, so five visits during breeding and non-breeding seasons may be enough to obtain a reasonable picture for that and the other two colonies not studied. This assumes that directions of foraging flights from the colony remain fairly constant. Two people and a boat would be required for 30 days for Trios, Sentinel Rock and White Rocks and for perhaps twice this in Pelorus Sound.

Note: If the studies of king shag diet (Project 3), their use of marine farms (Project 5, below) and the fish assemblages resulting from farms (Project 6) show that marine farms are compatible with king shags, the feeding range study would be largely redundant (Baxter, A. pers. comm.). If it appears that marine farms have a negative local effect on king shags, it becomes important to provide advice on where the farms should be located.

Project 5: Use of mussel farms by king shags

Objective: To further assess the use made of marine farms by shags to determine if such areas are selected or avoided for different behaviours.

Data on this issue could be collected during other studies, e.g. Projects 3 and 6. It would be a matter of quantifying the use shags were making of farms compared with nearby areas, and should include observations of how the installation of a farm changed the pattern of use of an area by shags. The experimental farm approach advocated in Project 6 (below) would be an ideal opportunity to investigate this question, or there are farm extensions that could be linked into.

Resources required: Minimal specific resources would be required if observations could be collected in a systematic way alongside other studies.

Project 6: Impacts of mussel farms on local fish stocks

Objectives: To describe any changes in fish stocks, density and composition, resulting from the placement of mussel farms, and assess likely impacts of any changes on king shags from knowledge of their diet (Project 3).

It has been suggested that one method would be to compare fish stocks around existing farms with stocks at similar sites with no farms. This would allow an assessment of the impacts of farms located mostly near-shore, but there would be some doubts whether the results could be extrapolated to farms in deeper water where the complete overlap with the foraging range of king shags occurs. We expect changes in sediments and water columns to be different in these areas, with their own flow-on effects to fish. The best approach to this issue would be a full BACI design assessing fish populations in four similar sites, then establishing marine farms at two chosen at random. The results would be strengthened by then removing these farms and measuring whether any changes to fish stocks were reversed. Such experimental farms would lend themselves to a lot of other research, e.g. on sedimentation and phytoplankton depletion.

The input of marine biologists is needed to design this research. It could involve the use of remote techniques (e.g. video cameras or sonar) as well as divers and would require significant resources.

The research projects proposed by the Ministry of Fisheries for 2002/03 include: 'The effects of marine farming on the marine environment and on wild fisheries resources' (Code: ENV 2002/14), which is pertinent to this issue. It includes looking at the specific effects of marine farms on blue cod and elephant fish (spawning), and the indirect effects on biodiversity resulting from changes in wave and current climate and from invertebrate predator aggregations under farms.

Project 7: Cumulative effects of mussel farms on the marine ecosystem

Objective: To assess the likely cumulative effects of farms to allow appropriate coverage to be determined for different sites to ensure no long-term damage to marine ecosystems.

This project has been written in the negative as the emphasis must be on avoiding negative changes such as reductions in diversity or threats to the populations of different taxa. However, it is recognised that filter-feeding bivalves are a natural part of the system and farms could theoretically have beneficial effects such as removing excess nutrients coming off farmed land.

This research requires a modelling approach as is being developed by NIWA in Beatrix Bay, alongside other work to obtain increasingly accurate estimates of the different parameters of the models and the interactions between them, for a variety of sites. Development of such a research programme will require the involvement of experts from several different disciplines and substantial funding. The Ministry of Fisheries proposed research project referred to above is also relevant.

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10. References

The Ministry of Fisheries is completing a literature review on the effects of marine farming. Some references which were not seen have been cited from other publications, e.g. Tenore & Gonzales (1975, cited in Kaiser et al. 1998) so the reader can go directly to the source of particular findings if required. Many of the references are unpublished and not readily available, but are the only sources of information.

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