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The Red-throated Diver (*Gavia stellata*) in human-disturbed habitats – building up a local population with the aid of artificial rafts

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Human actions, such as increasing recreational activity at lakes, have resulted in a deterioration in the quality of diver breeding grounds. We studied the breeding success of Red-throated Divers during 1994–2011 in Nuuksio National park in Southern Finland. We conducted an experiment in which we used peat hummocks to build floating nesting sites for the focal species. We used a population in Evo, South-Central Finland, as our control (i.e., no management). We found that the Nuuksio population increased steadily, and that the birds had a relatively high breeding success (pairs with a brood 73%, juveniles/pair 1.04). The index of juveniles per pair did not suggest density-dependence in the Nuuksio population. All except one nesting attempt at Nuuksio and Evo failed in mainland shoreline mire margins. Our results indicate that artificial nesting sites increase the breeding success of the Red-throated Diver. We assume that the mitigation of the effects of disturbance with management can improve brood production in the species.

1. Introduction

Breeding success may sometimes be a bottleneck for the self-sustained persistence of a local bird population. Limitations to breeding success may take place in various phases of the breeding season: from the nesting to the brooding phase (Newton 1998, Nummi & Saari 2003, Elmberg *et al.* 2005). The nesting phase alone can be critical; Martin (1993) concluded that the pervasive nature of nest predation indicates that nest sites are important habitat components, and that the nesting season can be a critical period for the maintenance of bird populations. Anthropogenic factors are also known to have an influence especially on the nesting phase of birds, either via direct disturbance (Hill *et al.* 1997, Carney & Sydeman 1999) or indirectly by removing essential nesting structures such as old trees (Virkkala *et al.* 1994). The effects of an absence of suitable structures have sometimes been successfully mitigated by providing nest boxes, as shown for waterfowl or Osprey (*Pandion haliaetus*) (Saurola & Sablevicius 1997). However, the nest site is often not the only limiting factor. Pöysä and Pöysä (2002), for example, found that the provision of extra nesting boxes

for breeding Goldeneyes (*Bucephala clangula*) increased the nesting success but not the number of fledglings; they interpreted this as a lack of suitable brood habitat.

The Diver is a genus of birds that has suffered from a low breeding success in many human-inhabited areas of its Holarctic range. In many boreal areas this is due mostly to large-scale anthropogenic factors, such as lake and mire drainage and increased human activity at lakes (Pakarinen 1997, Kauppinen & Pakarinen 1997, Piper *et al.* 2002). For example, Finland alone had almost half a million summer cottages at the end of 2009 (Anon. 2010a), most of which have been built near to shorelines. As a result, the breeding habitats of divers have severely deteriorated.

Nest predation is one of the most important factors affecting production of offspring in birds (e.g., Owen & Black 1990, Newton 1998). Overall, in divers and many other waterbirds, anthropogenically-enhanced predator populations and sometimes direct human disturbance have been suggested to negatively influence breeding success (Nordström *et al.* 2002, DeSorbo *et al.* 2007). Divers typically prefer to nest on islands over mainland sites, and their nesting performance is better in the former (Vermeer 1973, Lokki & Eklöf 1984), presumably due to lack of human disturbance and mammalian predators (Piper *et al.* 2002). Apart from nests, adults are also vulnerable to predation on dry land because of their limited ability to move on land (DeSorbo *et al.* 2008).

In some areas, reproductive success of divers has been increased with the aid of floating artificial rafts (Merrie 1996, Piper *et al.* 2002, DeSorbo *et al.* 2007). Studies have mainly concerned the Great Northern Diver (*Gavia immer*) of North America (Piper *et al.* 2002, DeSorbo *et al.* 2008), but in Scotland one investigation has also been conducted with the Black-throated Diver (*G. arctica*) and the Red-throated Diver (*G. stellata*) (Merrie 1996), and one with Black-throated Diver only (Hancock 2000). However, in no cases has a local breeding population been established in a new area.

Here we present a study of building up a productive local breeding population of the Red-throated Diver in a national park with continuously-increasing human recreational pressure. We conducted an experiment in which we built artificial, floating nesting rafts for Red-throated divers. Based on earlier studies (Lokki & Eklöf 1984, Merrie 1996) we hypothesized that Red-throated Divers would breed successfully on artificial rafts in spite of human disturbance during the nesting phase. Typically, humans (often with dogs) walk along lake shoreline paths. As a control (with no management), we used a Red-throated Diver population from an area 100 km northwards, which has very similar ponds but less human disturbance.

2. Material and methods

2.1. Study areas

Our study area includes the Nuuksio National Park and its surroundings, mostly a recreational area of the City of Helsinki (60°N, 20°E), situated in Southern Finland, 20 kilometres from the centre of the Helsinki metropolitan area with one million inhabitants. As a control, we used a Red-throated Diver population in Evo (61°N, 26°E), 100 kilometres north of Nuuksio. Study lakes and ponds in both areas are relatively small (Nuuksio 0.2–94.5 ha; Evo 0.1–49.5 ha) closed or headwater lakes. Their catchment area is mostly coniferous forest. Chemically most of the wetlands in Nuuksio can be characterized as being acid-sensitive clear water lakes with low pH and oligotrophic conditions. Most of the lakes in Nuuksio have only sparse emergent vegetation growing on the shoreline and some of them have narrow shore mire margins (Pätilä 1984, Nyberg *et al.* 2010). The lakes of Evo range from acid and oligotrophic lakes with sparse emergent vegetation to more eutrophic ones with belts of emergent vegetation on the shoreline. The lakes of Evo have fewer cliffs on the shoreline than those of Nuuksio (Nummi & Pöysä 1993, Arvola *et al.* 2010). The lakes of the two areas have previously been combined in studies of waterfowl and fish (Väänänen *et al.* 2012).

Our study took place during 1993–2011 (human disturbance measured in 2012); in the two first years we monitored the breeding success of Red-throated Divers. In the beginning of our study we monitored 84 lakes in Nuuksio. Later on we selected a subset of 54 lakes within the core of the Nuuksio lake area, thus leaving out lakes in the vicinity of year-round human settlement. During

1997–2009 the number of visitors to Nuuksio National Park increased from 60,000 to 180,000 visitors (Metsähallitus, unpubl. data). Most of them visit Nuuksio during the summer, which means that human disturbance strongly overlaps with the breeding season of divers. Twenty-nine of the 54 lakes are outside the national park. However, these lakes are also under heavy pressure from human recreational activity. In Evo we monitored 51 lakes. In Evo there were 60,000 visitors in 2009, and numbers also increased during the study period (Anon 2010b). In both areas, there was always only one breeding pair at each lake during the period of study.

2.2. Diver counts

We monitored Red-throated Divers in 1993–2011 by first observing the lake from the shore using binoculars, and then walking around it (Nummi & Pöysä 1993). In Nuuksio, we used three monitoring periods: the first from late April to early May after ice-melt; the second in mid-June and the third in July. If breeding success of divers could not be determined with certainty after the third count, we carried-out additional monitoring. In Evo, there were five monitoring periods: the first after ice-melt in late April or early May, the next two in early and late June and the final two in early and late July.

Red-throated Divers build visible nests on open-shore mire margins or on islands of small lakes (usually less than 5 ha). Nests are easy to find. In Nuuksio, our measures of the number of breeding pairs corresponded to the number of nests found. In Evo, nest-searching was not exhaustive, but most Red-throated Divers nested on a well-vegetated natural island. In the latter area, our measures of the number of breeding pairs corresponded to the number of pairs seen at least twice at a given lake during May–June.

We present two measures of juvenile productivity: (1) "brood" represents chicks of any age until fledging, and (2) "juveniles" are at least half-grown young (> 3 weeks old). The number of juveniles in this species generally corresponds with recruitment, since 92% of brood mortality takes place during the first two weeks after hatching (Mudge & Talbot 1993).

2.3. Construction of nesting rafts

We built artificial nesting sites for Red-throated Divers using peat hummock taken from the mire margin of the shore of the lake in question. The rafts were about 1 m^2 in size. We usually placed two waterproof 20-litre canisters under each raft to ensure that the raft was floating high enough (at least 15 cm) for Red-throated Diver nesting. Thus, our rafts were similar in appearance to the natural nesting sites of the focal species. Most of the raft was covered by *Sphagnum* moss, and *Carex* grasses, scrubs and occasionally tree saplings, which provided shelter for the incubating birds.

The rafts were placed at small lakes generally less than five and more than 0.5 hectares in size and which seemed to be suitable for the Red-throated Diver (undisturbed habitat, no buildings near the shoreline of the raft). Two of the rafts were placed at a lake with previous breeding attempts at the shore mire margin. Footpaths made by human visitors run along at least part of the shoreline of each of our raft lakes, and in two of the raft lakes, there is a summer cottage on the shore. We took this into account by placing each raft at the opposite end of the main source of human activity. Rafts were placed 25–50 m from the nearest shore; at this distance most of the incubating birds in Nuuksio stay on nests when humans walk along the shore (V.-M. Väänänen, pers. obs.). We placed only one raft per lake, and anchored each raft with a rope and a stone weight.

We built some new rafts yearly and restored old ones when necessary, e.g., when ice had broken them. The first rafts were built in late summer 1994. Since then, in addition to occupied rafts, we had 1–5 unoccupied rafts available annually for Red-throated Divers. The average yearly occupation rate was 0.63 (range 0.50–0.80).

2.4. Estimation of human disturbance

In 2012, in both Nuuksio and Evo, we calculated the number of lakes that had hiker(s) walking or staying at lake shores during our Mid-June survey, i.e., when Red-throated Divers are incubating. Only lakes with no permanent human settlement were considered (all 54 lakes in Nuuksio, 44 in Evo). In Nuuksio, we also measured peak distur-

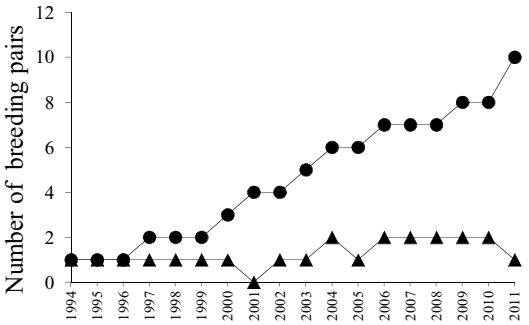

Fig 1. Number of Red-throated Diver breeding pairs in the Nuuksio (circles) and Evo (triangles) study areas in 1994–2011.

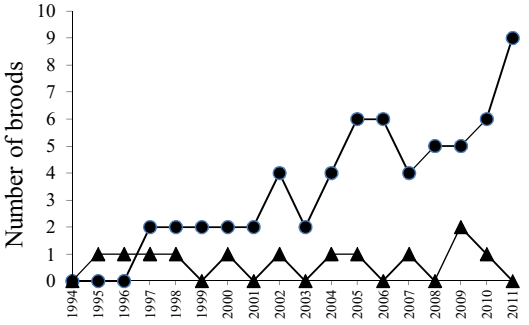

Fig. 2. Number of Red-throated Diver broods in the Nuuksio (circles) and Evo (triangles) study areas.

bance on 23 June 2012 (Midsummer Day) at the five lakes near to the guiding center and car park of the National Park. This is a part where there is an especially high rate of disturbance, yet in the vicinity there are five lakes with breeding Red-throated Divers.

3. Results

With the aid of rafts, the Nuuksio population of Red-throated Divers increased steadily between 1994 and 2001, from one pair to 10 pairs (Fig. 1). In the Evo control area, the population of Red-throated Divers varied between 1 and 2 pairs, during the period 2004–2011, with mostly 2 pairs observed. Similarly, the number of diver broods continuously increased in Nuuksio but remained stable in Evo (Fig. 2).

The cumulative number of Red-throated Diver broods during 1994–2011 was 51 in Nuuksio and 12 in Evo (Table 1). In Nuuksio, Red-throated Divers succeeded in producing 0.73 broods and 1.04 juveniles per pair, respectively. The corresponding figures for Evo were 0.52 and 0.65 (Table 1). In addition, the index of juveniles/pair of Red-throated Divers in Nuuksio remained stable despite the strong increase in pair numbers (Spearman rank correlation, R_s = 0.135, N = 17, P = 0.606; Fig. 3).

In Nuuksio, Red-throated Divers usually accepted the rafts within three years of placement. Records of the breeding success three years before and three years after the placement of rafts exist for ten lakes. In eight cases new pairs started to breed

Table 1. Red-throated Diver breeding parameters in the Nuuksio experimental and Evo control areas during 1994–2011.

Parameter	Nuuksio	Evo
Cumulative number of breeding pairs	84	23
Cumulative number of broods	61	12
Broods/ breeding pair	0.73	0.52
Cumulative number of juveniles	87	15
Juveniles/ breeding pair	1.04	0.65
Juveniles/brood	1.43	1.25

in the raft lakes, and in two they moved to breed on rafts (Sign test; $P < 0.01$). No significant change was found in the breeding status of Red-throated Divers on non-raft lakes in Nuuksio. The first breeding attempt in the Nuuksio study area was observed at a shore mire margin in the summer of 1994. This attempt was unsuccessful. We built a raft at this lake later in the same summer, and this raft has been occupied since the spring of 1995. In 2004, another pair bred unsuccessfully on the shore mire margin of another lake. Later in 2004, we built a raft to this lake, and this site has been continuously occupied since 2005. At both lakes, breeding has been quite successful after resettling from the shore line to the raft (0.75 juveniles/breeding attempt). Overall, in Nuuksio, Red-throated Divers have nested twice on shore mire margins and 12 times on natural islands, while the vast majority of breeding attempts (n = 69) have taken place on our rafts (2.4%, 14.5% and 83.1% of breeding attempts, respectively). In the Evo con-

Fig. 3. Number of Red-throated Diver juveniles per breeding pair in the Nuuksio study area in 1995–2011. The large circle indicates three data points and the medium-sized circle indicates two data points; each small circle indicates one data point.

trol area 11 out of 12 successful breeding events took place on islets.

The human disturbance rate at the 54 lakes of Nuuksio was 13% and that of the 44 lakes of Evo, 2%. The peak disturbance in the five lakes near the guiding center of the National park of Nuuksio was 10.4 persons per lake (4.4 groups per lake). Additionally, there were 1.2 dogs per lake. By one lake there were six tents and by another, one tent that was occupied overnight.

4. Discussion

In the Nuuksio experimental area, a Red-throated Diver population of one known territory with repeated nesting failures was revived to a growing and productive population with the aid of artificial rafts. Earlier studies have found increases in the breeding success of the Great Northern Diver (Piper *et al.* 2002, DeSorbo *et al.* 2008) and Red-throated Diver (Merrie 1996) in established populations. However, the population of Red-throated Divers studied by Merrie (1996) did not increase in spite of enhanced breeding success. In our study, the population of Red-throated Divers increased steadily from one to ten pairs in 2011 since the construction of the first rafts in 1994. During the same period the control population of Red-throated Divers in Evo remained relatively stable.

During the period of Red-throated Diver population increase, the production of juveniles remained at the level of one juvenile per pair without signs of density dependence. The breeding success of 1.04 juveniles/pair is near the upper end of the observed range of Red-throated Divers (0.51–1.15, Lokki & Eklöf 1984, Gomersall 1986).This figure indicates that the lack of suitable nesting places was indeed the bottleneck for the species in our study area. Food is not a limiting factor for Red-throated Divers in Nuuksio, since they only need these small lakes for nesting. Fish food for the young is mainly brought from the sea, about 20 kilometres away. This contrasts with the previously-cited case of Goldeneyes, where the increase in nesting pairs and brood production did not result in increased numbers of fledged ducklings (Pöysä & Pöysä 2002). With one juvenile per breeding attempt, it is possible that the Nuuksio population of Red-throated Divers has grown by its own production: in Shetland it has been estimated that 0.45 young per breeding pair is sufficient to maintain a stable population (Gomersall 1986). This is concordant with what has been found for divers more generally in Finland. Pakarinen (1989) calculated the production of fledglings required to maintain the Black-throated Diver population. With annual adult mortality rates from 9 to 13 per cent and the age of first breeding at 3 to 5 years, the annual production should be 0.29–0.75 juveniles per breeding pair. It is also likely that the Red-throated Diver has its life-cycle parameters within this range. However, having not marked the young, we do not know the immigration rate in our Nuuksio study population. This species tends to aggregate in loose colonies, and its

gregariousness seems to be partly independent of the species' fishing areas (Pakarinen 1997). The 0.65 juveniles per pair produced in Evo appears to be within the limits required to sustain a population.

The naturally-nesting Black-throated Divers in Nuuksio seem to face nest-site limitations as their breeding success strongly decreases with increasing pair density (V.-M. Väänänen & P. Nummi, unpublished data). This is probably due to the fact that, along with the population increase, a larger fraction of pairs are forced to breed on mainland (and not on islets or rafts). In our 18-year dataset, at the breeding lakes of Black-throated Divers without islands (5 lakes) the birds have bred successfully only once. The same situation might be true for the Red-throated Diver in Evo. For a long time, only one successful pair had its nest on an island. Another Red-throated Diver pair only started to breed continuously in another lake with an island after a Black-throated Diver pair had abandoned this nesting island, probably because of a cottage built by the lake. One successful and one unsuccessful shore-margin breeding attempt had taken place in the neighbouring lake prior to the successful attempt by the Red-throated Divers at this island lake.

The success of Red-throated Divers in Nuuksio has remained stable throughout the period of study. This was somewhat surprising given that the Nuuksio area is under continuous pressure from human recreational activity, and given that a great deal of disturbance takes place during the nesting phase. Divers are especially sensitive to disturbance during the nesting period (Lokki & Eklöf 1984, DeSorbo *et al.* 2007). It is obvious that Red-throated Divers tolerate higher disturbance when nesting in artificial nesting rafts surrounded by open water. In addition, the constant increase in the Red-throated Diver population is probably due to good juvenile production. Presumably young divers had already learnt to tolerate human activity during the brood stage, which in turn prepares them to nest at lakes with a high disturbance level.

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Kaakkuri ihmisen häiritsemässä ympäristössä – pesälauttojen rakentaminen paikallispopulaation tueksi

Ihmistoiminta, kuten ulkoilu ja retkeily järvillä, on vaikuttanut haitallisesti kuikkalintujen pesimäpaikkoihin. Tutkimme kaakkurin (*Gavia stellata*) pesimämenestystä 1994–2011 Nuuksion kansallispuistossa Etelä-Suomessa. Käynnistimme kokeen, jonka aikana rakensimme turpeesta kelluvia, lajille soveltuvia pesimäalustoja. Evolla eteläisessä Keski-Suomessa sijaitseva populaatio toimi verrokkina (ei kokeellista pesäpaikkojen lisäystä). Havaitsimme Nuuksion kaakkurikannan kasvavan tasaisesti, ja että lintujen pesimämenestys oli suhteellisen korkea (73 % pareista tuotti poikasia, 1,04 nuorta yksilöä paria kohti). Jälkimmäisestä laskettu indeksi viittasi siihen, ettei populaatioon vaikuttanut kannantiheys. Yhtä lukuun ottamatta kaikki Nuuksion ja Evon pesimäyritykset järven "mantereen" suorantaviivassa epäonnistuivat. Tuloksemme viittaavat siihen, että tekopesät ovat hyvä keino kohentaa kaakkurin pesimämenestystä. Oletamme häiriön vaikutuksien säätelyn ja ympäristön hoidon yhdessä auttavan lajin poikastuottoa.

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