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The impact of water level fluctuation on the breeding success of the Black-throated Diver *Gavia arctica* in South-west Sweden

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We evaluated the impact of water level fluctuation on the breeding success of the Black-throated Diver in South-west Sweden by using results from a one-year study of 43 lakes (49 pairs) in 1996 and surveys of a population of 16–22 pairs at the lake system Fegen-Svansjöarna in 1997–2000. At this lake system, the water level is regulated (for hydropower production) with a maximum amplitude of 1.75 m. In 1997–2000, an attempt was made to maintain a stable water level during the period 1 May–15 June. Flooding was the most important cause of breeding failure at the 43 lakes, whereas no failure could be related to this factor at Fegen-Svansjöarna. In the 43 lakes, the change in median water level during incubation was +6 cm for five flooded nests, compared to –5 cm for 14 hatched clutches and –6 cm for 13 clutches that failed because of other or unknown causes. The mean breeding success at Fegen-Svansjöarna was on the same level as for South-west Sweden in general during 1997–2000 (0.44 and 0.38 chicks per pair and year, respectively), but was higher than for the four years before the attempt to keep the water level stable (0.22 chicks). We conclude that flooding is a main cause of nesting failure, that rainfall is the main factor behind the water level fluctuations, and that the regulation of the water level for hydropower production may have an additional negative impact on some lakes. Control of the water level during the incubation period may help to reduce the risk of failure caused by flooding, and our results support previous recommendations to allow for a rise of only a few centimetres or a lowering of a maximum of 20–30 cm during the incubation period.

1. Introduction

In Europe, outside Russia, about 99% of the Black-throated Divers *Gavia arctica* breed in Sweden, Finland, Norway and Scotland, with a few additional pairs in the Baltic countries and Belarus (as concluded in Tucker & Heath 1994). The current estimate of the breeding population in Sweden is 5,500–7,000 pairs (Eriksson & Lindberg 1998; SOF 2002), and populations in Norway and Finland are of the same magnitude, comprising a total of 17,000–20,000 pairs (Asbirk *et al.* 1994). Thus, the management of Black-throated Diver populations in the Nordic countries is of vital importance for the long-term survival of the species in a European perspective.

During the last decades, divers (Gaviidae) have been given high priority in bird conservation and wildlife management, both in North America and northern Europe (e.g. Lindberg 1968; McIntyre 1988, 1994; Eriksson 1994), due to concern about a presumed low breeding success in combination with a complex of potential threats. The preferred breeding habitat of the Black-throated Diver is oligotrophic freshwater lakes larger than 0.1 km² (e.g. Eriksson *et al.* 1995 and Lindberg & Eriksson 1998 for South-west Sweden). Previous field studies have primarily dealt with problems related to disturbance from outdoor recreation and fluctuating water levels (e.g. Eriksson 1987; Götmark *et al.* 1989; Eriksson *et al*. 1995), but effects linked to freshwater acidification, such as reduced availability of fish prey and increased exposure to toxic heavy metals, have also been studied (e.g. Eriksson *et al.* 1992; Eriksson 1994; McNicol *et al.* 1995).

The Black-throated Diver places its nest very close to the shoreline, usually less than 1 m from the shore (e.g. Lehtonen 1970; Götmark *et al.* 1989), and thus nests are very susceptible to flooding even with only a moderate rise in the water level during the incubation period. In several studies in Sweden, Finland and Scotland (e.g. Andersson *et al.*1980; Götmark *et al.*1988, 1989; Campbell & Mudge 1989; Pakarinen 1989; Mudge & Talbot 1993 and Eriksson *et al.* 1995), flooding of nests has been identified as a main reason for nest failures. In a recent literature overview of the potential impact of water level fluctuation on various bird species in Finland (Ahola *et al.* 2003), the Black-throated Diver was judged to be the species that was most heavily affected, although a negative impact was also recorded for the Tufted Duck *Aythya fuliga*, Common Gull *Larus canus*, Common Tern *Sterna hirundo*, Arctic Tern *Sterna paradisea* and Marsh Harrier *Circus aeruginosus*. The water level fluctuations are related both to natural impact from rainfall (e.g. Eriksson *et al.* 1995) and human impact in terms of the regulation of the water level, e.g. for hydropower production (e.g. Götmark *et al.* 1988, 1989), or a combination of both factors (e.g. Pakarinen 1989; Mudge & Talbot 1993). In Scotland during the 1990s, when floating nesting rafts were provided for Black-throated Divers in an attempt to reduce the negative impact of water level fluctuations, the breeding success of the birds increased by 44% (Hancock 2000).

Other diver species seem to be less susceptible to fluctuations in the water level. The Red-throated Diver *Gavia stellata* mostly nests by small lakes and tarns (often smaller than 0.1 ha) on quagmire shores and islets that to some extent float with the water level fluctuations (Dahlén & Eriksson 2002). In North America, the Great Northern Diver *Gavia immer* frequently uses nest sites on floating bog islets or marshland shores, an adaptation which is thought to reduce the risk of flooding (McIntyre & Barr 1997).

Thus, there are indications that water level fluctuation may be an important factor to consider in the management of breeding habitats for the Black-throated Diver. In order to analyse the impact of this factor in some detail, we have used results from a one-year study of 43 lakes, holding 1–3 pairs each, and the outcome of a voluntary agreement with water-rights owners over a four-year period to keep the water level stable during spring and early summer in a large lake system holding 16–22 pairs.

2. Methods

2.1. Study area

2.1.1. 43 lakes in South-west Sweden

In 1996, we investigated the breeding performance of 49 Black-throated Diver pairs, distributed among 43 lakes (median lake surface area: 0.88 km², range: 0.19–7.40 km²) within an approximately 9,000 km² area in South-west Sweden (approx. 57º40'N, 12º25'E; Fig. 1). For 18 of the lakes (42%), the water level is regulated, mainly for hydropower production. Amplitudes range between 0.2 and 6.0 m, but in only three of the lakes is it greater than 2.0 m. The lakes were included in a study of breeding success in relation to the water chemistry in 1994–1997 (Eriksson & Hake 2000).

Twenty-nine of the lakes (67%) were also included in previous but more extensive surveys from the late 1960s and onwards, most of them coordinated by Södra Älvsborgs Ornitologiska Förening until 1992 (e.g. Eriksson 1987; Ahlgren *et al.* 1993; Eriksson *et al.* 1995), and from 1994 within the framework of the national survey of divers in Sweden ("Projekt LOM"; e.g. Eriksson, Hake & Lindberg 2002). In these studies, around 42% of the lakes were regulated, about 40% had an amplitude less than 1.0 m, another 40% had amplitudes between 1.0 m and 2.0 m, and the remaining ones had amplitudes up to 6.0 m. Results from the previous studies showed that breeding success did not differ between the regulated and non-regulated lakes, but for the period 1982–1992 a significant relationship between breeding success and rainfall could be confirmed (Eriksson 1987; Eriksson *et al.* 1995). Thus, rainfall was more important than regulation of the water level as an indirect factor affecting the breeding success.

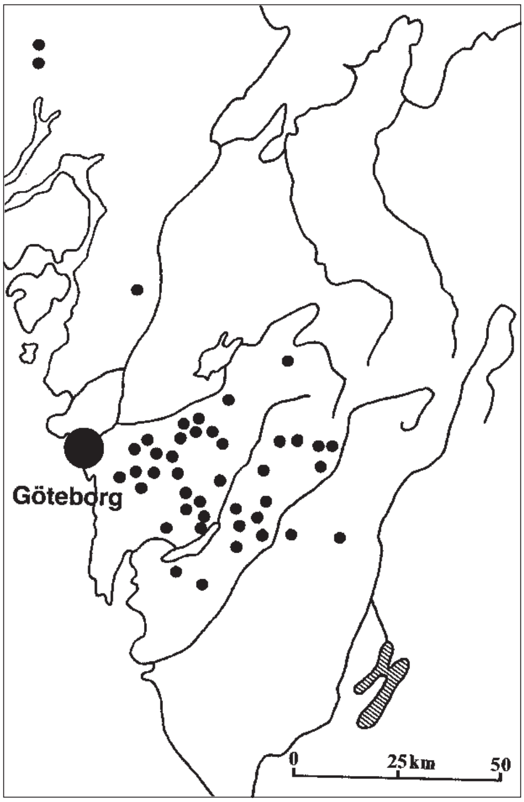

Fig. 1. Location of the study area in South-west Sweden: Filled circles = lakes investigated in 1996, hatched area = Fegen-Svansjöarna.

2.1.2. Fegen-Svansjöarna

We also investigated the breeding success of a population of 16–22 pairs in a single lake system, Fegen-Svansjöarna (total surface area 24.7 km², 57º10'N, 13º05'E; Fig. 1). The water level is regulated by a system of weirs for hydropower production, with a legal permit allowing for a maximum amplitude of 1.75 m. Götmark *et al.* (1988, 1989) concluded that the regulation had a major direct impact on the water level and an indirect effect on the breeding success of the Black-throated Diver population. In 1997–2000, an attempt was made to maintain a stable water level during 1 May–15 June, under a voluntary agreement with the water-rights owners. We compared the breeding performance in 1997–2000 with previous work done in the same lake system in 1974, 1979 and 1983–84 (Alexandersson 1979; Götmark *et al.* 1988, 1989, 1990).

The attempt to maintain a stable water level was not entirely successful (Table 1). The level rose by 13 cm during the first two weeks of the period 1 May–15 June in 1997, but thereafter it remained stable throughout this period. In 1998, there was a continuous drop of 14 cm over the study period and in 1999 the water level dropped by 9 cm in May, followed by a rise of 6 cm during the first two weeks of June. In 2000, the water level dropped by 6 cm from 1 May to 15 June. Except for 1997, however, the water level fluctuations were kept within the previously recommended interval in order to avoid a negative effect on the breeding success of the Black-throated Divers, in other words, to allow for a rise of only a few centimetres or a lowering of 20–30 cm during the incubation period (Götmark *et al.* 1988). In contrast,

Table 1. Breeding success of the Black-throated Diver at Fegen-Svansjöarna and, for comparison, in South-west Sweden; for the years 1974, 1979, 1983, 1984 and 1997–2000.

	Fegen-Svansjöarna			South-west Sweden	
Year	1	2	Reference	1	Reference
	No control of the water level during the incubation period at Fegen-Svansjöarna				
1974	0.10 (20)	–49 cm	Alexandersson (1979)	No data	–
1979	0.05 (20)	+32 cm	Alexandersson (1979)	0.38 (32)	Eriksson & Lindberg (1997)
1983[3]	0.44 (18)	+10 cm	Götmark *et al.* (1988)	0.46 (59)	Eriksson & Lindberg (1997)
1984[3]	0.30 (20)	–31 cm	Götmark *et al.* (1988)	0.40 (57)	Eriksson & Lindberg (1997)
Mean per year	0.22			0.41	
	Water level controlled during the incubation period at Fegen-Svansjöarna				
1997	0.38 (16)	+13 cm	This study	0.54 (87)	Projekt LOM
1998	0.53 (19)	–14 cm	This study	0.36 (67)	Projekt LOM
1999	0.56 (18)	–9 cm	This study	0.24 (66)	Projekt LOM
2000	0.27 (22)	–6 cm	This study	0.38 (45)	Projekt LOM
Mean per year	0.44			0.38	

1 Mean number of “large” chicks per resident pair (number of pairs)
2 Change in water level, 1 May–10 June
3 Recalculated and adjusted as compared to previously published data, with reference to the cross-check against primary data (Annex 1 in Götmark *et al.* 1988).

the water level fluctuations were not kept within this interval for any of the years 1974, 1979, 1983 and 1984 (Table 1).

In order to investigate whether reproduction at Fegen-Svansjöarna reflected a general pattern within a larger area, we compared breeding success at this lake system with overall breeding success in South-west Sweden during the same period, using results from the above-mentioned voluntary surveys. From these surveys we selected data from lakes located in the provinces of Västergötland (formerly Älvsborgs län), Bohuslän and North and Central Halland, e.g. from the region covered by Eriksson (1987) and Eriksson and Lindberg (1997). The number of lakes surveyed each year varied between 32 and 87.

2.2. Breeding success

The main purpose of the field work was to confirm the presence of any resident pairs and the survival of chicks. During the fieldwork, active and abandoned nest sites were checked, and the presence of adult birds and chicks was recorded. We assessed a “resident pair” to be present in a territory if recorded on at least two occasions with an intervening time of two weeks or more during May–July or if breeding was confirmed with information on a nest with eggs or incubating birds. We measured “breeding success” as the number of “large” (i.e. half-grown to fledged) chicks per resident pair, making our results comparable to earlier studies as well as to the current national survey of divers in Sweden (“Projekt LOM”). We defined a “successful breeding” as a breeding attempt resulting in at least one “large” chick.

For the various lakes, the number of visits and the decision to make observations from either the shore or boats were determined with reference to the need to collect satisfactory data for accurate and comparable assessments of the presence of resident pairs and breeding success. The 43 lakes surveyed in 1996 were visited 3–6 times between 1 May and 22 August. Observations were made while canoeing around the entire lake (including all islets) or from the shore, depending on which approach gave the best possible overview of the

Table 2. Criteria used for the classification of causes of breeding failure.

Cause of failure	Criterion
Flooding	Evident from field inspections that incubation had been interrupted due to a rise in water level, e.g. nest found drowned.
Stranding	Evident from field inspections that a drop in water level had made it very difficult for an adult diver to reach the abandoned nest.
Predation	Eggshells found within sight of the nest (however, predation by an egg robber carrying the egg over some distance may have been overlooked).
Human persecution	Obvious signs that eggs had been destroyed by humans, i.e. signs that could not possibly be the work of a mammal or bird predator known to occur in the study area.
Disturbance – outdoor recreation	Only when there was an obvious connection between breeding failure and observation of disturbance, such as a visit to the breeding islet or a boat close to the nest.
Hatched but chicks lost	Chicks hatched, but no records of “large” chicks during following field visits.
Unknown cause of failure	Not possible to relate to any of the causes above.

lake. At Fegen-Svansjöarna, a small out-board engine boat was used to check all Black-throated Diver territories 2–10 times during May–August.

In order to evaluate the relative importance of water level fluctuation in relation to other factors, we classified the possible causes of breeding failure, using a conservative approach based on field observations, as shown in Table 2.

Our judgements might be biased, as some causes of failure, e.g. flooding due to a rise in the water level, were easier to confirm in the field than others e.g. stranding, predation or disturbance. Unfortunately, it is impossible to avoid this kind of biased data, unless the records are based on very intensive observation, as done by Götmark *et al.* (1990) at Fegen-Svansjöarna in 1983 and 1984, or by using time-lapse surveillance cameras, as in a study in Scotland in 1986–87 (Mudge & Talbot 1993).

2.3. Assessment of dates for the start of incubation, nest failure and hatching

The date of various events, such as the start of incubation, interrupted breeding or hatching, was calculated with the Mayfield method (Mayfield 1961, 1975; Johnson 1979; Beintema 1996). We assumed that a specific event occurred midway between two successive visits at the breeding site, and when two events had taken place between successive visits, we split the time between the two visits into three equally long periods (allowing for an arbitrariness of ±1 day if the number of days was not equally divisible by three). We used the Mayfield method only in order to match dates of various events with readings of the water level (see below). The total number of exposure days for each area and year was too low with the Mayfield method to analyse breeding success, following the recommendation by Beintema (1996).

2.4. Assessment of water level fluctuations

For 26 lakes out of the 43 investigated in 1996, we used gauges to record water level fluctuations, where available, or we marked poles, stones or other objects. We assessed the water level on the day when a specific event, such as the start of incubation, hatching or nest failure took place, by assuming a linear change between two readings. This may have introduced a source of error, as undetected fluctuations in water level might have occurred between two readings. For Fegen-Svansjöarna, the water level was recorded daily, providing more accurate information than for the lakes studied in 1996.

For the analyses, we primarily used data from first clutches. Data from replacement clutches

Table 3. Causes of breeding failure for first clutches of the Black-throated Diver in South-west Sweden, 1996–2000.

Cause of failure	43 lakes 1996	Fegen-Svansjöarna 1997	Fegen-Svansjöarna 1998	Fegen-Svansjöarna 1999	Fegen-Svansjöarna 2000
Flooding	8 (35%)	0	0	0	0
Stranding	2 (9%)	0	0	0	0
Predation	3 (13%)	6 (50%)	1 (9%)	0	5 (50%)
Human persecution	1 (4%)	0	0	0	0
Disturbance – outdoor recreation	1 (4%)	1 (8%)	0	0	1 (10%)
Hatched but chicks lost	1 (4%)	0	0	1 (10%)	0
Unknown cause of failure	7 (30%)	5 (42%)	10 (91%)	9 (90%)	4 (40%)
Total	23	12	11	10	10

were used only if information about the first clutch by the same pair was incomplete. We never included data from both first clutches and replacements for the same pair and year.

3. Results

3.1. The 1996 study in 43 lakes

The mean breeding success of the 49 pairs studied in 1996 was 0.43 “large” chicks per resident pair, i.e. on the same level as the average of 0.46 “large” chicks per pair and year recorded in South Sweden (Götaland) during 1994–2001 (Eriksson *et al.* 2002). Breeding success was numerically higher among 24 pairs breeding in regulated lakes, 0.50 “large” chicks per resident pair compared to 0.36 “large” chicks per resident pair for 25 pairs breeding at non-regulated lakes, but the difference was not statistically significant (P = 0.38, Mann-Whitney U test, $n_{regulated}$ = 24 lakes, $n_{non\text{-}regulated}$ = 25 lakes).

Flooding or stranding due to fluctuations in the water level accounted for 44% of the nest losses (Table 3). Flooding was the most important single factor; eight out of 23 nests (35%) were judged to have failed due to this cause, and two nests (9%) were abandoned after a drop in the water level. Other causes of failure were predation (3 nests), human persecution (1 nest) and disturbance due to outdoor recreation (1 nest). For as many as seven nests (30%), however, we were not able to draw any conclusion about the probable cause of failure.

Almost all failures were recorded during incubation, and only one failure could be related to the disappearance of all chicks after hatching. For 12 nests located at regulated lakes, failure due to flooding was confirmed for six (50%) of them, compared to two (18%) out of 11 nests located at non-regulated lakes (Table 4). Although this result might indicate a higher risk of failure due to flooding of nests located at regulated lakes, the difference was not significant (P = 0.25, Fisher exact test).

Among the 32 nests at the 26 lakes where recordings of the water level could be matched both with the date of the start of incubation and with hatching or nest failure, the median change in the water level during incubation was –5 cm (range: –19 to +5 cm) for 14 hatched clutches, and –6 cm

Table 4. 2 × 2 contingency table for comparison of the proportion of nest failure due to flooding at regulated and non-regulated nests at the 43 lakes investigated in 1996. Data are for the same nests as in Table 3.

	Number (%) of nests	
	Nests located at regulated lakes	Nests located at non-regulated lakes
Failure due to flooding	6 (50%)	2 (18%)
Failure due to other or unknown reason	6 (50%)	9 (82%)

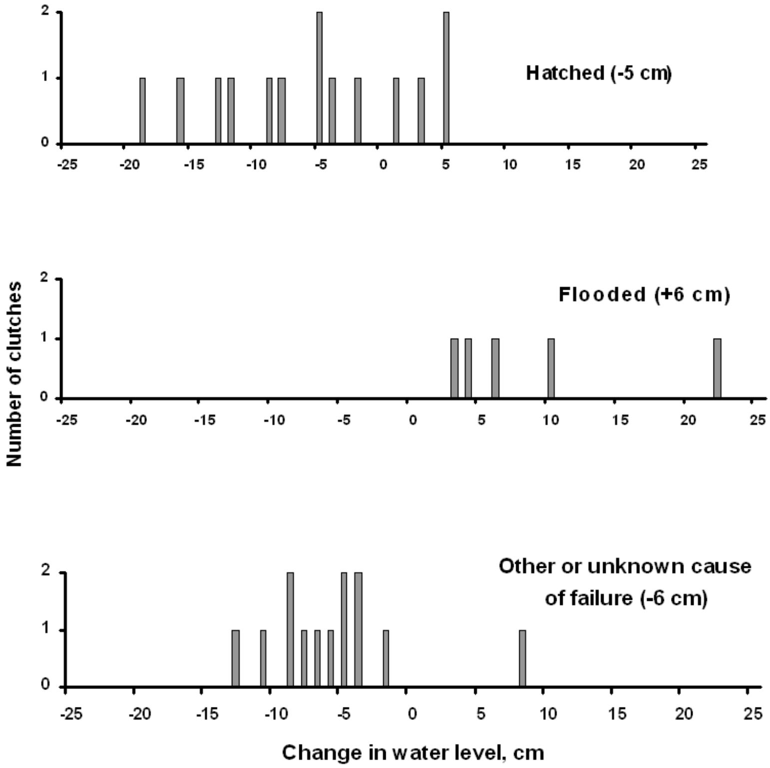

Fig. 2a. Change in the water level during incubation of 32 clutches investigated in 1996. Dates for the occurrence of events, such as the start of incubation, hatching or failure, were calculated with the Mayfield method. Median changes in the water level are given in parentheses (Kruskal-Wallis one-way analysis of variance, KW = 9.71, df = 2, $P < 0.01$).

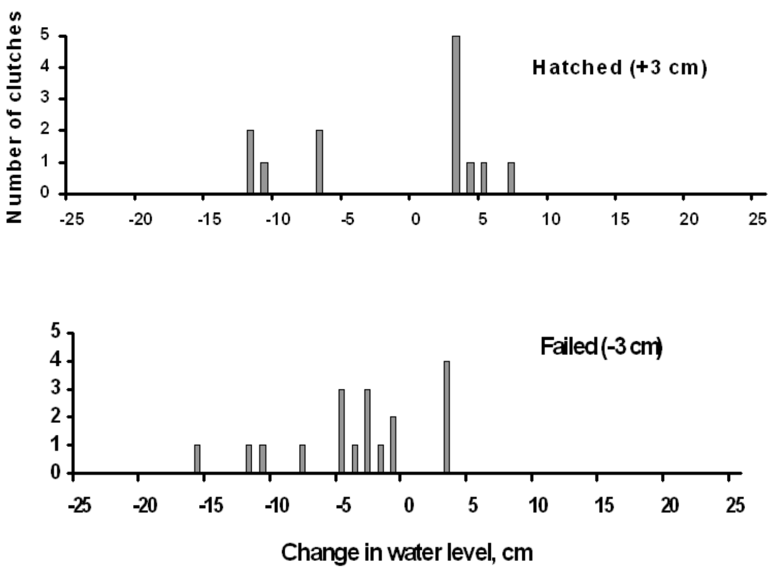

Fig. 2b. Change in the water level during incubation of 31 first clutches at Fegen-Svansjöarna, 1997–2000. Dates for the occurrence of events, such as the start of incubation, hatching or failure, were calculated with the Mayfield method. Median changes in the water level are given in parentheses (Mann-Whitney U test, $P = 0.22$; but, as data are pooled, dependencies resulting from information on the same pair during more than one year may have affected the result).

(range: –13 to +8 cm) for 13 clutches which failed due to unknown causes or causes other than flooding (Fig. 2a). In contrast, flooded nests were exposed to a median rise in the water level of +6 cm (range: +3 to +22 cm). No clutch exposed to a rise in the water level by more than 5 cm hatched, and single nests were abandoned already after a rise of 3 cm (Fig. 2a).

3.2. Fegen-Svansjöarna

At Fegen-Svansjöarna, the average breeding success was higher for the period 1997–2000 when the water level was controlled during 1 May–15 June than it was for the four study years (1974, 1979, 1983 and 1984) before the attempt was made to maintain a stable water level, 0.44 and 0.22 "large" chicks per pair and year, respectively (Table 1). Although the difference was numerically high, it was not statistically significant ($P = 0.20$, Mann-Whitney U test, $n_{1974–1984} = n_{1997–2000} = 4$ years).

The average breeding success in South-west Sweden in 1979, 1983 and 1984 (no data from 1974) was almost the same as during 1997–2000, 0.41 and 0.38 "large" chicks per pair and year, respectively (Table 1). Thus, there was no indication that the low reproduction recorded at Fegen-Svansjöarna before the attempt was made to keep the water level stable reflected any general regional tendency. During 1997–2000, i.e. when the water level was kept stable, the breeding success at Fegen-Svansjöarna was on the same level as for South-west Sweden in general, 0.44 and 0.38 "large" chicks per pair and year, respectively (Table 1).

No failures due to flooding or stranding were recorded at Fegen-Svansjöarna during 1997–2000 (Table 3), although there was an indication that one nest classified as "unknown cause of failure" in 1998 was destroyed after exposure to waves. The cause of failure could not be identified for two-thirds of the failed nests. Predation could be confirmed in 12 cases and disturbance due to outdoor recreation in two cases. As for the 43 lakes investigated in 1996, almost all failures were recorded during incubation and only one case of disappearance of all chicks could be confirmed.

The median change in the water level during the incubation period for 13 hatched nests was +3 cm in 1997–2000 (range: –12 to +7 cm, Fig. 2b), and only three of them survived a water level rise of more than 3 cm. No clutches were flooded (see above), and for the 18 clutches that failed due to unknown causes or causes other than flooding, the median change in the water level was –3 cm (range: –16 to +3 cm). The difference between the two groups was not significant ($P = 0.20$, Mann-Whitney U test, $n_{hatched} = 13$, $n_{failed} = 18$, Fig. 2b).

4. Discussion

4.1. Impact of water level fluctuation on the breeding success of Black-throated Divers

Flooding seemed to be the most important cause of breeding failure for the Black-throated Divers breeding at the 43 lakes investigated in 1996, accounting for around one-third of the losses during incubation. We judge this conclusion to be quite robust, as we believe it is easier to correctly assess when a nest has been flooded compared to most of the other potential factors (as listed in Table 2). In a Scottish study that used surveillance cameras, flooding was responsible for 31% of the losses (Mudge & Talbot 1993), and flooding was also identified as a main factor of failure in a survey of the Black-throated Diver population in Finland in 1985–86 (Pakarinen 1989). The negative impact of water level fluctuation during the nesting period has also been noted in previous Swedish studies during the 1970s and later (e.g. Andersson *et al.* 1980; Eriksson *et al.* 1995). But Lehtonen (1970) did not address the potential impact of water level fluctuations in his classic study of Lake Suonteenjärvi, in Finland in 1962–68, apparently because the water level regularly dropped by around 7 cm from the middle of May until the beginning of July in his study area and this event did not seem to trouble the divers very much.

Although our results support previous conclusions that water level fluctuation, and especially flooding, is a main cause of nesting failure, we found no indications that human impact in terms of the deliberate regulation of the water level was a main indirect factor among the lakes investigated in 1996. Even though 18 (42%) of them were regulated, there was no indication of higher breeding success between regulated and non-regulated lakes, i.e. a result consistent with previous findings from studies in South-west Sweden (Eriksson 1987; Eriksson *et al.* 1995). For the period 1982–1992, Eriksson *et al.* (1995) found a significant negative relationship between the amount of rainfall in May and the production of young in South-west Sweden, suggesting that rainfall was the main factor affecting the water level fluctuations and thus indirectly the breeding success.

For individual lakes, however, water level regulation probably has an important impact. At Lake

Oulujärvi in Finland, which is used as a reservoir for hydropower production, about 70% of the Black-throated Diver nests were judged to be flooded during a survey in the 1980s, and at Lake Päijänne a very low breeding success of only 0.05 fledged chicks per pair was ascribed to a combined effect of water level regulation and human disturbance (Pakarinen 1989). In the Scottish study, Mudge and Talbot (1993) concluded that although flooding primarily was to be regarded as a natural factor, the impact of flooding had probably been magnified because of adjustments at the outlets to satisfy angling interests and the regulation of the breeding lakes for hydropower production.

The results from Lake Fegen-Svansjöarna indicate that the attempt to maintain a stable water level in 1997–2000 helped to reduce the negative impact of water level fluctuations. No nest losses could be attributed to flooding or stranding, and there was an indication (statistically not significant) of improved breeding success. In 1983, when the water level rose by 10 cm during 1 May–10 June, at least three breeding attempts (13% of 18 resident pairs that year) failed because of flooding, and there were signs of a negative effect on another four nests; whereas, a drop of 31 cm in 1984 had less of a negative impact (although breeding success nevertheless was lower than in 1983 due to other factors; Götmark *et al.* 1988). After reviewing the records of water level fluctuations in the lake system during 1960–1986, Götmark *et al.* (1988) also concluded that fluctuations in the water level probably had an important negative impact on the breeding success during at least 15 out of 27 years.

In conclusion, flooding was a main cause of failure at the 43 lakes investigated in 1996, and rainfall was the main factor that affected the water level fluctuations in the breeding lakes. The results from Lake Fegen-Svansjöarna indicate that keeping the water level stable during the incubation period may reduce the risk of flooding of nests.

4.2. Other causes of breeding failure

In order to evaluate the impact of water level fluctuation on the breeding success of Black-throated Divers, other potential causes of breeding failure should also be taken into account. If we take a conservative approach (Table 2), the figures given in Table 3 are minimum assessments, and considering the risk of biased estimates with reference to the difficulties in correctly assessing different causes of failures, conclusions must be drawn with caution.

Several studies in Sweden, Finland and Scotland (Lehtonen 1970; Götmark *et al.* 1988, 1990; Campbell & Mudge 1989; Mudge & Talbot 1993) indicate that predation is a main cause for nesting failures. We assessed that predation was the second most important cause of failure at the 43 lakes investigated in 1996, and the main cause at Fegen-Svansjöarna. Previous studies at Fegen-Svansjöarna showed that birds, mainly corvids and larids, were the main predators (Götmark *et al.* 1988). At Lake Suonteenjärvi in Finland, predation by the Hooded Crow *Corvus corone cornix* was the most important factor for nest losses (Lehtonen 1970). In Scotland, however, nocturnal mammalian predators, such as the Red Fox *Vulpes vulpes*, the Pine Marten *Martes martes* and the Otter *Lutra lutra*, seemed to be more important than in our study (Campbell & Mudge 1989).

Only a small proportion (4–10%) of the breeding failures could be related to human disturbance. The breeding lakes of Black-throated Divers are often used for outdoor recreation, such as fishing, bathing and canoeing, and the risk of failure due to disturbance has been repeatedly addressed (e.g. Andersson *et al.* 1980; Campbell & Mudge 1989; Eriksson 1987; Eriksson *et al.* 1995; Götmark *et al.* 1988, 1989, 1990; Mudge & Talbot 1993). The evidence is not entirely conclusive, however, as it is difficult to find good indicators of disturbance. In South-west Sweden, previous studies did not show any relationship between breeding success and the number of houses or boats along the shores of the breeding lakes (Eriksson 1987; Eriksson *et al.* 1995). In a Scottish study, no indication of a difference in breeding success between lakes with high or low activity by anglers could be detected (Campbell & Mudge 1989). In other studies, however, a lower breeding success in years with nice weather during weekends in May has been associated with a potential negative effect of outdoor recreation (e.g. Götmark *et al.* 1988; Pettersson 1985; Douhan 1997).

Failures due to predation and disturbance are difficult to separate, as the risk of predation may be enhanced if an incubating bird leaves the nest when disturbed by boats or humans (Götmark *et al.* 1989, 1990). Also, a loss due to predation or disturbance may be more difficult to confirm than a failure caused by water level fluctuation. Thus, failures due to predation or disturbance probably make up a major part of the breeding attempts classified as "unknown cause of failure". Finally, it is surprising that the Black-throated Diver is still an object of human persecution (Table 3), as was also noted in Scottish studies (Campbell & Mudge 1989).

4.3. Management recommendations

Based on the results of this and previous studies, we conclude that flooding is a main cause of nesting failure for the Black-throated Diver, that rainfall is a main indirect factor behind the water level fluctuations, and that human impact in terms of water level regulation may have an additional effect at least on the local level and for individual lakes. Keeping the water level stable during the nesting period may help to reduce the risk of flooding, and our results also support previous recommendations to allow for a rise of only a few centimetres or a lowering of 20–30 cm of the water level during the incubation period (Götmark *et al.* 1988), i.e. May and June for the majority of the pairs in South and Central Sweden, although replacement clutches may hatch later during the summer. The positive experiences from artificial floating islands, used to increase reproduction in lakes with large water level fluctuations in Scotland (Hancock 2000), should also be considered in the preparation of future management strategies.

The occurrence of Black-throated Divers during the breeding season is a main justification for the designation of several freshwater lakes in Sweden and Finland as Special Protected Areas (SPA) within the Natura 2000 network of protected areas in the European Union, and in accordance with the European Community Directive on the conservation of wild birds (known as the Birds Directive, 79/409/EEC). Control of the water level during the incubation period should be considered in the management plans for any regulated freshwater lake designated as an SPA with reference to the Black-throated Diver, to ensure a favourable conservation status in accordance with the obligations under the Birds Directive.

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Vattenståndsvariations inverkan på storlommens häckningsresultat i sydvästra Sverige

För att utvärdera betydelsen av variationer i vattenståndet för storlommens häckningsutfall analyserade vi resultat från en ettårstudie av 43 sydvästsvenska sjöar med 49 stationära par 1996 och från undersökningar 1997–2000 av en population på 16–22 par i sjösystemet Fegen-Svansjöarna i sydvästra Sverige (fig. 1). 18 (42 %) av de 43 sjöar som inventerades 1996 är reglerade med amplituder mellan 0,2 och 6,0 m och fungerar som vattenmagasin för elproduktion eller kommunalt dricksvatten. Fegen-Svansjöarna regleras med en amplitud på maximalt 1,75 m. 1997–2000 genomfördes ett försök med att hålla en stabil vattennivå i sjösystemet under perioden 1 maj–15 juni. För att undersöka eventuella effekter på storlommens häckningsresultat använde vi uppgifter från inventeringar 1974, 1979, 1983 och 1984 som en referens för situationen före försöket med en konstant vattennivå. Vi relaterade också häckningsresultatet i Fegen-Svansjöarna till uppgifter från mer heltäckande inventeringar av storlommens häckningsframgång i sydvästra Sverige.

Bland de 43 sjöarna (med 49 storlomspar) som undersöktes 1996 var variationer i vattenståndet den viktigaste enskilda orsaken till att häckningar misslyckades under ruvningen, och 35 % av de misslyckade häckningarna kunde kopplas till att bona översvämmats efter ett stigande vattenstånd (tabell 3). Häckningsframgången var 0,43 ”stora” ungar per par, och således i nivå med ett genomsnitt på 0,46 ”stora” ungar per par och år i Götaland under perioden 1994–2001, och ungproduktionen låg på samma nivå för par häckande vid reglerade och icke reglerade sjöar.

För 32 bon vid 26 av de 43 sjöar som undersöktes 1996 kunde datum for ruvningens början och slut (p.g.a. av misslyckande eller kläckning) relateras till förändringar i vattenståndet. För fem häckningar som övergavs efter att bona översvämmats var den genomsnittliga förändringen en höjning av vattennivån på 6 cm (medianvärde), medan vattennivån sjönk med i genomsnitt 5 cm och 6 cm (medianvärden) för kläckta kullar respektive kullar som misslyckats av annan eller okänd anledning (fig. 2a).

Vid Fegen-Svansjöarna kunde ingen av de misslyckade häckningarna relateras till fluktuerande vattennivå. Häckningsframgången vid Fegen-Svansjöarna låg på samma nivå som för sydvästra Sverige i övrigt under 1997–2000 (0,44 resp. 0,38 ”stora” (halvvuxna–flygga) ungar per par och år, tabell 1), och den var väsentligt högre än genomsnittet på 0,22 ”stora” ungar per par och år under åren innan försöket med en stabil vattennivå inleddes, även om skillnaden inte kunde fastställas med s.k. statistisk signifikans.

På basis av resultat av våra egna undersökningar och tidigare studier i Sverige, Finland och Skottland bedömer vi att variationer i vattenståndet och därav följande översvämmade bon är en viktig orsak till att storlommens häckningar misslyckas. Vanligtvis är det i första hand regn som orsakar de variationer i vattenståndet som påverkar storlommens häckningsutfall, men reglering av vattennivån kan förstärka denna negativa effekt. Erfarenheterna från Fegen-Svansjöarna visar att man genom att sträva efter en stabil vattennivå under storlommens ruvningsperiod kan minska risken för att häckningar misslyckas på grund av variationer i vattenståndet. Våra resultat ligger i linje med tidigare rekommendationer om att man bör begränsa variationerna i vattenståndet under ruvningsperioden till en höjning av vattennivån på högst några få centimeter eller en sänkning på 20–30 cm, om man önskar anpassa vattenståndsvariationerna så att risken för att storlomshäckningar misslyckas minskar. För reglerade sjöar som förordnats som “särskilda skyddsområden” (SPA) i enlighet med EU:s fågeldirektiv och med hänsyn till bl.a. storlommen, bör föreskrifter om en konstant vattennivå under ruvningsperioden ingå i skötsel- eller bevarandeplaner, om man skall tillgodose de krav på en s.k. gynnsam bevarandestatus som fågeldirektivet ställer.

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