Dose dependent effects of plumage-oiling on thermoregulation of Common Eiders *Somateria mollissima* residing in water

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Thermoregulatory effects which occur during the first hours after plumage-oiling were studied under laboratory conditions by measuring the metabolic heat production of Common Eiders (*Somateria mollissima*) which were resting in water for up to three hours. The ducks were exposed to 10–70 mL Statfjord A crude oil while residing in water inside a respiration chamber at 5.5°C. The study demonstrated a dose- and time-dependent effect of plumage oiling on metabolic heat production during the first three hours after contact with the oil. The results indicate that the immediate, short-term effects following initial contact with oil at sea are lesser in scale than those which occur after the birds have preened the oil into a greater part of their plumage. After plumage contamination with 70 mL crude oil, the rate of heat loss exceeded the thermoregulatory heat production capacity and the Eiders became hypothermic within 70 minutes after contamination.

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Introduction

Several studies have demonstrated that ingested petroleum hydrocarbons have toxic effects on birds. These effects may be lethal to young birds, whereas for adult birds ingestion of oil generally seems to have sublethal effects (see reviews by Holmes 1984; Leighton et al. 1985). The effects of external oiling on plumage insulation and thermoregulation are probably the major cause of the high mortality found among seabirds following oil spills at sea.

Plumage oiling affects the thermoregulatory ability of birds because the oil adheres to the feathers and disrupts the water-repellent properties of the plumage. Thus, water penetrates into the plumage and removes the insulating layer of air which is normally entrapped within the feather coat. Heat loss is increased, and in order to remain homeothermic, plumage-oiled birds increase their rate of metabolic heat production (Hartung 1967; McEwan & Koelink 1973; Lambert et al. 1982; Jenssen & Ekker 1988; 1989; 1990).

Because of the high thermal conductivity and heat capacity of water, the rate of heat loss from an oiled bird which resides in water is much higher than that of an equally oiled bird which resides in air of the same temperature (Jenssen & Ekker 1990). The heat loss of oiled birds that reside in water may thus exceed their heat production capacity, leading to hypothermia (Erasmus et al. 1981; Jenssen & Ekker 1988; 1990). Hartung (1967) and McEwan & Koelink (1973) have reported dose-dependent effects of plumage oiling on the thermoregulation of ducks residing in air. We have previously shown that the metabolic rate of Domestic Ducks *Anas platyrhynchos* being contaminated with 500 mL and 2000 mL crude oil and residing in water was 49% and 162%, respectively, higher than the normal value (Jenssen & Ekker 1989). No other studies seem to have been made on a possible dose-dependent effect of plumage oiling on birds residing in water.

The present study aimed at elucidating possible, short-term dose-dependent effects of plumage oiling on the thermoregulation of Common Eiders *Somateria mollissima* which were residing in seawater at 5–6°C. A situation in which

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Common Eiders were swimming into an oil slick at sea was simulated under laboratory conditions. The effects on thermoregulation occurring during the initial 1–3 hours after contact with the oil were studied by measuring the rate of metabolic heat production following exposure to 10–70 mL Statfjord A crude oil.

Material and methods

Experimental birds

Twelve Common Eiders (body weight, 2.10 ± 0.24 kg) were caught in Trondheimsfjorden (63°26′N, 10°24′E), Norway, during the winters of 1985 to 1987. Prior to the experiments, the ducks were kept indoors with access to a freshwater pool (1 × 3 × 1 m), at air temperatures between 3 and 10°C and water temperatures between 4.5 and 6°C. During captivity, the birds were given a light regime that corresponded to the local latitude and time of year. They received a diet of blue mussels *Mytilus edulis* and mashed fish.

Heat production

The oxygen consumption ($\dot{V}O_2$) of absorptive Common Eiders was measured in an open-circuit system (Depocas & Hart 1957). After being weighed the birds were placed in a respiration-chamber (70 liters) filled with 25 liters of seawater. To keep both air and water temperatures stable at 5.5 (±0.5)°C, the respiration chamber was placed inside a constant-temperature cabinet. Air was passed through the system at a rate of 8–15 L min^{-1} by means of a suction-pump (Reciprotor 506R). The air was dried with Silica-gel and the flow measured continuously with a calibrated flowmeter (Cole Parmer Instrument Company, FMO34-39ST). A fraction of the air was directed into an oxygen-analyser (Servomex Series 1100) for determination of the O_2 content which was continuously recorded on a Watanabe Servocorder (SR 6310). Prior to each experiment, the O_2-analyser was calibrated against atmospheric air (20.95% O_2) and gaseous nitrogen (0% O_2). Oxygen consumption (mL O_2 g^{-1} h^{-1}) was calculated according to the equation:

$$\dot{V}O_2 = \dot{V}_E \frac{(F_{IO_2} - F_{EO_2})}{1 - (1 - RQ)\,F_{IO_2}}$$

given by Withers (1977), in which $\dot{V}E$ is the airflow (mL STPD min^{-1}) leaving the respiration-chamber. F_{IO_2} and F_{EO_2}, respectively, are the fractions of O_2 in the air entering and leaving the respiration chamber. RQ is the respiratory quotient, which was assumed to be 0.85 for an absorbtive bird. Heat production (H) was calculated by assuming an energetic equivalent of 5.571 W kg^{-1} per mL O_2 g^{-1} h^{-1}.

Temperature measurements

The air and water temperatures in the respiration chamber were recorded close to the air outlet and 10 cm below the water surface, respectively. Body temperature was measured after each experiment, by inserting a copper-constantan thermocouple 10–15 cm into the bird's colon.

Experimental protocol

All the birds were allowed to adapt to the experimental conditions in a mock experiment. In the actual experiments, the ducks were allowed to adjust to the new situation for at least one hour before data collection started. Before being exposed to the oil, the metabolic rate of each bird was monitored for 30 minutes. The intended amount of Statfjord A crude oil (with a temperature of 5°C) was added to the water in the respiration chamber through a tube 1 cm below the surface. Thus, the birds were exposed to the oil without human disturbance, and a situation in which the birds were swimming into an oil slick was simulated. The metabolic heat production of each bird during subsequent 10-minute periods, from 30 minutes prior to oil-exposure and up to 180 minutes after exposure, was then calculated.

Two of the Common Eiders were exposed to 10 mL crude oil, two other Eiders to 15 mL, one to 25 mL, one to 30 mL, two to 35 mL, one to 40 mL, one to 50 mL, and two to 70 mL. In addition one control experiment, where seawater was injected into the chamber while the duck was resting quietly on the water, was conducted on one of the Eiders before it was exposed to oil.

Results

Only a negligible fraction of the oil introduced into the water adhered to the wall of the res-

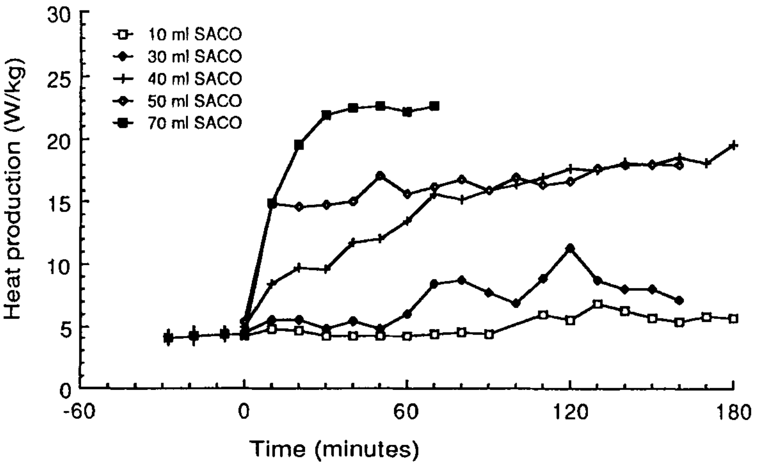

Fig. 1. Metabolic heat production (W kg^{-1}), expressed as a function of time, of five Common Eiders (*Somateria mollissima*) exposed to different dosages of Statfjord A crude oil while residing in water.

piration chamber, and after a bird was removed from the chamber, only a thin layer of oil was seen on the water surface. Thus, more or less all the oil which had been introduced into the respiration chamber was assumed to have been absorbed onto the bird's plumage. After all the experiments, oil was observed on the plumage of the birds. However, only in ducks exposed to more than 25 mL crude oil were the deeper lying parts of the plumage wet.

During the baseline period prior to oiling, the mean resting metabolic heat production of the Common Eiders was 4.39 W kg^{-1} (n = 12, SD = 0.65). Following exposure to 10–15 mL crude oil, there was only a small, transient rise in heat production, indicating that exposure to small amounts of oil had no effect on plumage insulation (Fig. 1). Exposure to 25–70 mL oil resulted in an increase in heat production which was correlated with both the exposure load and the time elapsing after the initial contact with the oil (Figs. 1 and 2). Exposure to 35–50 mL crude oil produced an immediate increase in heat production, which levelled off at approximately 200–250% above the baseline leel. Following exposure to 70 mL, heat production increased until, after approximately one hour, it reached the birds' maximal capacity for thermoregulatory heat production, which is approximately 20–25 W kg^{-1} (Jenssen & Ekker 1988). After 70 minutes, when the experiments with the two birds exposed to 70 mL crude oil were terminated, their body temperatures were 38.2 and 37.9°C, respectively. In Eiders contaminated with 10–50 ml Statfjord crude oil,

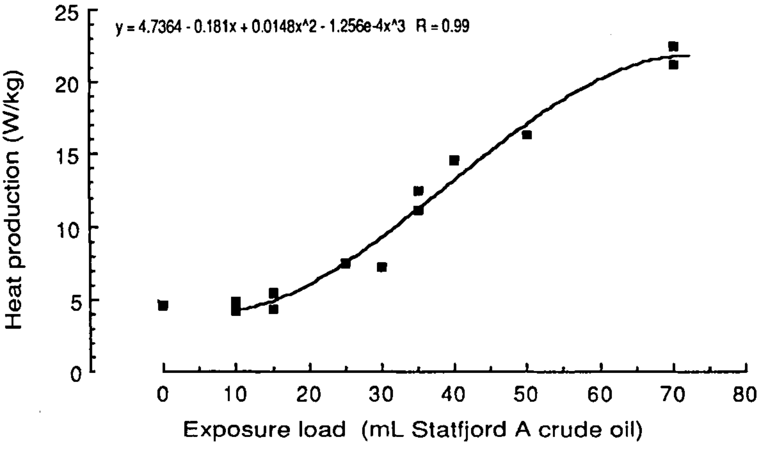

Fig. 2. Heat production (W kg^{-1}) of 12 Common Eiders (*Somateria mollissima*) residing in water, expressed as a function of exposure load (mL Statfjord A crude oil) one hour after exposure.

there was no correlation between exposure load and terminal body temperature, which had a mean value of 40.7°C (n = 6, SD = 0.4).

Discussion

The results of the present study have demonstrated that a clear relationship exists between the amount of crude oil to which the Common Eiders were exposed and the scale of the resultant effect on metabolic heat production. Oiling of Common Eiders with 10 and 15 mL Statfjord A crude oil had no effect on metabolic heat production during the first three hours after exposure to the oil. Exposure to small amounts of oil does not therefore seem to have any immediate effect on plumage insulation capacity. Following exposure to ⩾20 mL oil, heat production increased as a function of the exposure load and the time following initial contact with the pollutant.

The effects of the oil on thermoregulation increased as a function of the time, probably because of the time taken for the oil and water to be absorbed into the plumage. The time-dependent increase in heat production may also have been a result of the birds having preened the oil into their plumage. However, the limited space inside the respiration chamber could have prevented the Eiders from preening properly, compared to the situation in nature where birds can preen freely. The results from the present study may therefore underestimate the immediate effects of plumage oiling.

Dose dependent effects of plumage oiling on thermoregulation have been reported for Mallards *Anas platyrhynchos*, Black Ducks *Anas rubripes* and Scaups *Aythya marila* (Hartung 1967; McEwan & Koelink 1973) kept on land (exposed to air). Hartung (1967) demonstrated that, during exposure to an air temperature of 0°C, contamination of Black Ducks with 5, 10 and 20 g lubricating oil led to increases in the metabolic rate of 35, 57 and 87%, respectively. These corresponded to increased heat losses of the oiled Black Ducks by 44, 64, and 88%, respectively. McEwan & Koelink (1973) demonstrated that the minimal thermal conductance (heat loss) of Scaups exposed to 50, 100 and 200 mL Boundary Lake crude oil for one hour was 34, 26 and 94%, respectively, greater than the normal value. Hartung (1967) demonstrated that during exposure to an air temperature of −10°C, contamination of a single Mallard with 15 g fuel oil resulted in almost a 100% increase in the metabolic rate, while Lambert et al. (1982) found that oiling with 12 mL Prudhoe Bay crude oil for 1 hour led to an 8% rise in the metabolic rate of Mallards exposed to an air temperature of −12°C. Because all the studies referred above were made on oiled birds resting in air on land, the effects on the metabolic rate were small when compared to the almost 400% increase in heat production recorded for our Eiders after exposure to 70 mL Statfjord A crude oil.

The greater effect on metabolic heat production recorded in the present study was because the oiled Eiders were resting in water during their exposure to the oil. Since the thermal conductivity and thermal capacity of water is much greater than that of air, the heat loss from the two Eiders exposed to 70 ml crude oil exceeded the birds' maximal thermoregulatory heat production capacity, resulting in hypothermia. Hypothermia in birds with oiled plumages swimming in water has also been recorded for Jackass Penguins, *Spheniscus demersus*, with approximately 70% of their plumage surface covered with oil (Erasmus et al. 1981), and for Common Eiders contaminated with 12.5 mL crude oil (Jenssen & Ekker 1990). In the present study the body temperature of the Eiders exposed to 10–50 mL oil lay within the normal range for healthy Eiders (Jenssen et al. 1989).

We have shown in another study (Jenssen & Ekker 1990) that exposure of Common Eiders to 12.5 mL crude oil resulted in their metabolic heat production reaching its maximum possible level, and the birds became hypothermic. In the present study, exposure to similar amounts of the same oil apparently had no effect on metabolic heat production. This discrepancy is probably explained by the fact that the oiled Eiders in our former study were allowed to preen before they were placed on water in the respiration chamber for the metabolic rate to be recorded. When birds preen their oiled plumage, the contaminating oil probably becomes spread over a greater part, and also into deeper parts, of the plumage. This increases the wettability of the plumage and thus induces a greater decline in the insulation capacity of the plumage. Lambert et al. (1982) presented results that also support this suggestion. Immediately after a one-hour exposure of Mallards to 12 mL crude oil while residing in water, their metabolic rate, at an air temperature of −12°C, was 7% above the normal value. Four to fourteen days after plumage oiling, the metabolic rate, immediately after being taken out of water and placed in air in the respiration chamber, was 12% above the normal value. Also, Mallards exposed to 2.5 mL Statfjord A crude oil mixed with a chemical dispersant had a 160%–315% higher heat production while residing in water on the day following contamination, than two to three hours after exposure to the pollutant (Jenssen & Ekker 1991). Thus, it seems as though the effect of oiling on thermoregulation is greatly enhanced when the oil is spread over a greater part of the plumage, due to the birds' preening activity, and the long-term thermoregulatory effect of plumage oiling would seem to be considerably greater than the immediate, short-term effect after the initial contact with oil at sea.

In a previous study we demonstrated that contamination of Domestic Ducks with 500 mL and 2000 mL Statfjord A crude oil caused their metabolic heat production to increase by 49% and 162%, respectively, while residing in 21°C water. The relatively small effect on the metabolic rate of domestic ducks following exposure to these large doses may be due to that oiling affects the plumage of various species differently. The low metabolic response can also be explained by the higher water temperature in the experiments with the Domestic Ducks.

The present study was conducted in the laboratory, and one must therefore remain aware of its limitations. In a situation in nature, the effects of external contamination will be modified by several factors. The thickness of the oil slick and the activity of the bird within the slick will be decisive in determining the amount of oil that is absorbed into the plumage. Assuming that all the oil with which a bird comes into contact is absorbed by the plumage, an Eider, which has a width of approximately 15 cm, has only to swim through a 6.7 m stretch of oil spill with a thickness of 0.1 mm to absorb 70 mL oil. In order to absorb 70 mL oil when swimming through a layer of blue-shine, which has a thickness of approximately 1 μm, a Common Eider would have to swim through a 670 m stretch of the slick. McEwan & Koelink (1973) reported that the thermal conductance of Mallards exposed to 200 mL Bounday Lake crude oil for 1, 2 and 4 hours increased by 13, 58 and 74%, respectively, above the normal value. Thus, the time that a bird is in contact with the slick will also influence the amount of oil and water that is absorbed into the plumage. We have shown elsewhere (Jenssen & Ekker 1991) that the effect on heat production after external exposure to an oil-dispersant mixture was greater for Common Eiders than for Mallards. This suggests that the plumages of different species tolerate oil contamination to different degrees. Finally, the viscosity of the oil probably also has an influence on how much oil is absorbed by the plumage (Bourne & Bibby 1975).

Since plumage-oiling of birds reduces their thermal insulation and causes a resultant increase in the metabolic rate, birds that are not so badly oiled that they become hypothermic and die must increase their feeding activity in order to remain in homeostasis. Increased time spent on feeding will reduce the time available for other activities, for example such as reproduction and feeding of chicks. Butler et al. (1988) demonstrated that contamination of the plumage of adult Leach's Storm-petrels (*Oceanodroma leucorhoa*) reduced the survival rate of their chicks. This effect may be attributed to the adults' needing more time for feeding in order to compensate for their increased energy expenditure for remaining normothermic.

Since the thermal conductivity and thermal capacity of water is much greater than that of air, the thermoregulation and energetics of diving birds will be more affected by plumage oiling compared to aerial and semi-aquatic species. This may help to explain why more diving species than aerial species were killed following the EXXON VALDEZ spill in March 1989, where 260,000 barrels of crude oil leaked into Prince William Sound, Alaska, and probably killed a total of 100,000–300,000 birds (Piatt et al. 1990).

In conclusion, this study has demonstrated that there is a dose-dependent effect of plumage oiling on the thermoregulation of Common Eiders during the first few hours after contact with the oil. Together with the results of other studies (Jenssen & Ekker 1990), this paper indicates that the immediate, short-term effect after the initial contact with oil at sea, is less than the effect noted after the birds have had time to preen the oil into a greater part of their plumage.

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