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ROTENONE USE AND SUBSEQUENT PREY LOSS LOWERS OSPREY FLEDGING RATES VIA BROOD REDUCTION

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ABSTRACT.—Fisheries managers used the fish toxicant rotenone to eradicate an undesirable brown bullhead (*Ameiurus nebulosus*) population and all other fish species at Hyatt Reservoir, Oregon, on 12 October 1989. This 4-yr study (1988–1990, 1992) compared effects of that rotenone project on Ospreys (*Pandion haliaetus*) nesting at Hyatt Reservoir and nearby Howard Prairie Reservoir (untreated reference)—the latter a reservoir where both brown bullheads and hatchery-released rainbow trout (*Oncorhynchus mykiss*) prospered. Because Hyatt Reservoir was treated after Osprey fall migration in 1989, the first 2 yr (1988 and 1989) yielded pretreatment information: number of Osprey pairs was unchanged and reproductive rates were similar and consistent at the two reservoirs. Yearling fish (200–250 mm) were restocked at Hyatt Reservoir in the spring of 1990 and Ospreys returned each year following rotenone treatment, with no decline in the number of occupied or active nests. The negative effect of the rotenone treatment on Ospreys was short-term, resulting in reduced reproductive rates (young/occupied nest, young/active nest, and young/successful nest) during the first nesting season posttreatment, although hatching rates were not affected. Osprey dive success and prey delivery rates declined sharply in 1990, leading to competition for food among siblings and brood reduction. Osprey reproductive rates and prey delivery rates at Hyatt Reservoir in both 1990 and 1992 remained below the extremely high pretreatment rates, but within the range required for population stability. Serious adverse effects of the fish loss on Osprey reproduction were minimized by: (1) the delay of the rotenone application until after breeding season, (2) the restocking of the treated reservoir in the following spring with some larger (yearling) fish (though the timing was late), (3) the maintenance of a supplemental feeding program for a nesting pair of Bald Eagles (*Haliaeetus leucocephalus*), which minimized kleptoparasitism on Ospreys, and perhaps most important (4) the presence of nearby water bodies, where Osprey obtained some fish in the 1990 and 1992 breeding seasons.

KEY WORDS: *Osprey*; Pandion haliaetus; *brown bullhead*; Ameiurus nebulosus; *brood reduction*; *nesting population*; *prey delivery rate*; *prey loss*; *reproduction*; *rotenone*.

EL USO DE ROTENONA Y LA SUBSIGUIENTE PÉRDIDA DE PRESAS DISMINUYEN LAS TASAS DE CRÍA DE *PANDION HALIAETUS* MEDIANTE REDUCCIÓN DE LA NIDADA

RESUMEN.—Los administradores pesqueros utilizaron rotenona, un compuesto tóxico para los peces, con el fin de erradicar una población indeseable de *Ameiurus nebulosus* y todas las demás especies de peces en el embalse Hyatt, Oregón, el 12 de octubre de 1989. Este estudio de cuatro años (1988–1990, 1992) comparó los efectos de ese proyecto de erradicación utilizando rotenona sobre los individuos de *Pandion haliaetus* que anidan en el embalse Hyatt y en el embalse cercano Howard Prairie (referencia sin tratamiento), siendo este último un embalse donde prosperaron tanto *Ameiurus nebulosus* como *Oncorhynchus mykiss*, ambas especies liberadas de criadero. Debido a que el embalse Hyatt fue tratado después de la migración otoñal de *P. haliaetus* en 1989, los primeros dos años (1988 y 1989) arrojaron información previa al tratamiento: el número de *P. haliaetus* y las tasas reproductivas fueron similares y consistentes en los dos embalses. Los peces de un año (200–250 mm) fueron repoblados en el embalse Hyatt en la primavera de 1990 y las águilas regresaron al año siguiente del tratamiento con rotenona, sin una disminución en el número de nidos ocupados o activos. El efecto negativo del tratamiento con rotenona en *P. haliaetus* fue a corto plazo, lo que resultó en una reducción de las tasas reproductivas (nido joven/ocupado, nido joven/activo y nido joven/exitoso) durante la primera temporada de nidificación posterior al tratamiento, aunque las tasas de eclosión no se vieron afectadas. El éxito de las inmersiones de las águilas y las tasas de aporte de presas disminuyeron

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drásticamente en 1990, lo que provocó competencia por la comida entre hermanos y la reducción de la cría. Las tasas reproductoras de *P. haliaetus* y las tasas de aporte de presas en el embalse Hyatt en 1990 y 1992 se mantuvieron por debajo de las tasas extremadamente altas del pre-tratamiento, pero dentro del rango requerido para la estabilidad de la población. Los efectos adversos graves de la pérdida de peces en la reproducción de *P. haliaetus* se redujeron al mínimo mediante: (1) el retraso de la aplicación de rotenona hasta después de la temporada reproductiva, (2) la repoblación del embalse tratado en la primavera siguiente con algunos peces más grandes (de un año), aunque el momento fue tardío, (3) el mantenimiento de un programa de alimentación suplementaria para una pareja de *Haliaeetus leucocephalus*, que minimizó el cleptoparasitismo en *P. haliaetus*, y quizás lo más importante, (4) la presencia de cuerpos de agua cercanos, donde *P. haliaetus* obtuvo algunos peces en las temporadas reproductivas de 1990 y 1992.

[Traducción del equipo editorial]

INTRODUCTION

Rotenone is a natural plant toxin used for centuries by indigenous peoples of Southeast Asia and South America to harvest fish for human consumption (Ling 2003). Fisheries managers in North America began using rotenone to control unwanted fish species in the 1930s. Between 1988 and 2002, rotenone was used in 38 states (annually in 26) and five Canadian provinces (McClay 2005), continuing a trend of use by at least 35 states for more than 50 yr (McClay 2000). In the State of Washington since 1940, 508 lakes were treated and 283 (55.7%) more than once (Hisata 2002). Rotenone is still in use as a fish management tool that is guided by standard operating procedures (Finlayson et al. 2018).

Finlayson et al. (2000) reported very low rotenone residues (<0.1 mg/kg [ww]) in dead fish following treatments, and rotenone residues were not readily absorbed by species eating dead fish. Rotenone persistence in natural waters varies from a few days to several weeks depending on the season; it is one of the most environmentally benign toxicants available for fisheries management (Ling 2003). However, although secondary toxicity of rotenone to fish-eating birds or mammals is of limited concern, effects of reduced food supplies on local fish-eating bird populations following fish removal started to receive attention by the 1970s (Koplin 1971). Ospreys (*Pandion haliaetus*) nesting near inland lakes or reservoirs require waters with abundant medium-sized (150–350 mm) fish species vulnerable to capture near the surface (Lind 1976, Swenson 1978, Van Daele and Van Daele 1982, Hagan and Walters 1990), and generally located within 1.6 km of nest sites, but sometimes 3–10 km away (Garber 1972, Airola and Shubert 1981, Henny and Kaiser 1996, Ewins 1997). Clearly, Ospreys seek to minimize energy expenditure whenever possible and nest close to fish resources, but have some flexibility, though perhaps at a cost to their reproductive success.

Prey species of Ospreys often include less desirable or "rough" fish species: suckers (Catostomidae); chub, peamouth (*Mylecheilus caurinus*), pikeminnow, and carp (Cyprinidae); bullhead/catfish (Ictaluridae); bluegill (*Lepomis macrochirus*) and crappie (Centrarchidae; Vana-Miller 1987). It is noteworthy that these slow-moving, sometimes overpopulated, and easy to catch rough fish are often the target species for Ospreys and also for fish eradication projects using rotenone. The largest users of rotenone in North America include states with the largest inland populations of Ospreys, which use rough fish as their primary prey (Houghton and Rymon 1997, McClay 2005).

Many Osprey populations in the USA, including those in Oregon, were greatly reduced during the 1950s and 1960s due to pesticides (primarily dichlorodiphenyltrichloroethane [DDT], which was banned in 1972), but when this field study was conducted (1988–1992), many populations had begun to recover (Henny et al. 2010). This study provided a unique opportunity to determine whether food limits reproductive success in Ospreys, and if so, at what stage. Regarding the temporary reduction in food supplies until fish numbers were restored, the American Fisheries Society (AFS) rotenone use manual (Finlayson et al. 2000) noted "There is no indication that this temporary reduction results in any significant impacts to most bird or mammal populations because most animals can utilize other water bodies as sources of food." However, the AFS also mentioned several mitigation options including Bald Eagle (*Haliaeetus leucocephalus*) egg removal to an approved program (State of California 1991) and treatment schedule changes.

Here we evaluate possible food shortages and reproductive effects on an Osprey nesting population due to an operational sport fisheries restoration

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project by the Oregon Department of Fish and Wildlife (ODFW) using rotenone at Hyatt Reservoir (treatment); we compare those findings with another Osprey population nesting at nearby Howard Prairie Reservoir (reference area) in southern Oregon—hereafter, Hyatt and Howard Prairie. At Hyatt, all or nearly all fish (mostly brown bullheads *(Ameiurus nebulosus*) were killed with rotenone (autumn 1989), but then the reservoir was restocked by ODFW (spring 1990) with limited numbers of yearling (200–250 mm) rainbow trout (*Oncorhynchus mykiss*), winter or spring steelhead (anadromous form of rainbow trout), and largemouth bass (*Micropterus salmoides*)—hereafter, bullhead, trout, steelhead, and bass, plus fingerling (75-130 mm) trout and bass. Untreated Howard Prairie was chosen as the reference area because of its large Osprey nesting population, its abundance of bullheads and trout, and its nearby location, so that other natural processes, e.g., weather (Johnson et al. 2008), water levels (Houston et al. 2010), predation (Poole et al. 2002), and nest site selection (all in live or dead trees of same species) would not muddle a comparison of annual reproductive rate.

The objective of this comparative study was to determine how a migratory Osprey population would react upon returning to nest sites at a formerly fish-abundant reservoir, and how long any reproductive problems documented might persist. Possible Osprey responses included: (1) all birds depart the reservoir prior to initiating nesting as found by Allen et al. (2007) for nesting Western Grebes (*Aechmophorus occidentalis*) at a lake in Minnesota following autumn rotenone treatment, (2) some pairs depart, (3) birds stay but do not lay eggs, (4) pairs lay eggs but fledge fewer young, or (5) pairs lay eggs and fledge pretreatment numbers of young.

Methods

Study Areas. *Hyatt Reservoir (Hyatt).* The 387-ha Hyatt (42°11.17′N, 122°27.23′W), located 23 km east of Ashland, Oregon, and just west of the crest of the Cascade Mountain Range at an elevation of 1529 masl (Fig. 1), was created by damming Keene Creek in 1923 to store water for irrigation. It is maintained by the US Bureau of Reclamation (BOR) and managed by the Talent Irrigation District (TID). Reservoir average depth is only 5.5 m, with well-mixed water and transparency limited to 1.7 m. Productivity is classified as high, or eutrophic (Johnson et al. 1985). Controlled outflow from Hyatt Dam flows 1.9 km downstream to Little Hyatt Reservoir (5.2 ha), hereafter Little Hyatt, then 3.5 km down Keene Creek before entering Keene Creek Reservoir (5.9 ha), which is generally drained and filled each week to maintain constant flow in the irrigation system and is generally fishless due to wide fluctuations in water levels. Little Hyatt is maintained at full pool for recreational purposes.

Hyatt was stocked with warm-water fish shortly after its formation and managed for those species until 1960 when ODFW first used rotenone to reduce the stunted fish population prior to restocking with bass, bluegill, and trout (ODFW 1997). Rotenone was used by ODFW at Hyatt two more times (1967 and 1977) to remove/control introduced undesirable warm-water fish (primarily bullheads) to restore the popular trout fishery. Although some trout and bass were still present at Hyatt in 1988, the familiar pattern reappeared with an estimated 7.5 million stunted bullheads (approximately 150 mm in length) dominating the reservoir based on beach seine sampling on 18 September 1988 (ODFW 1997, D. Haight and M. Jennings pers. comm.). Then, in mid-May 1989, many bullheads died. The removal of all bullheads was deemed necessary and rotenone was used again by ODFW on 12 October 1989 (12 yr after previous treatment).

Howard Prairie Reservoir (Howard Prairie). The 805-ha Howard Prairie (42°12.98′N, 122°22.58′W) reference area is in the Klamath Basin and located just east of the Cascade Mountain crest at an elevation of 1380 masl, 4.4 km northeast of Hyatt (Fig. 1). It was created by damming Grizzly Creek in 1957–1958 and has an average depth of 11 m. All physical, chemical, and biological parameters indicate mesotrophic conditions (Johnson et al. 1985). The project was built by BOR and operated as a major component of the TID. Controlled outflow from the reservoir and nearby streams is directed into the Howard Prairie Canal to Keene Creek Reservoir, where it joins the flow from Hyatt and leaves the Klamath Basin via the Cascade Divide Tunnel to the Rogue River Basin for irrigation.

Trout have been stocked in the reservoir since 1959. Several other fish species were probably introduced by anglers. Bullheads were first detected there in 1964, with pumpkinseeds (*Lepomis gibbosus*) and golden shiners (*Notemigonus crysoleucas*) found in 1972. Since 1986, Howard Prairie has been managed for hatchery trout and bullheads, and annually stocked with 250,000 to 350,000 fingerling trout. The reservoir is one of the most productive

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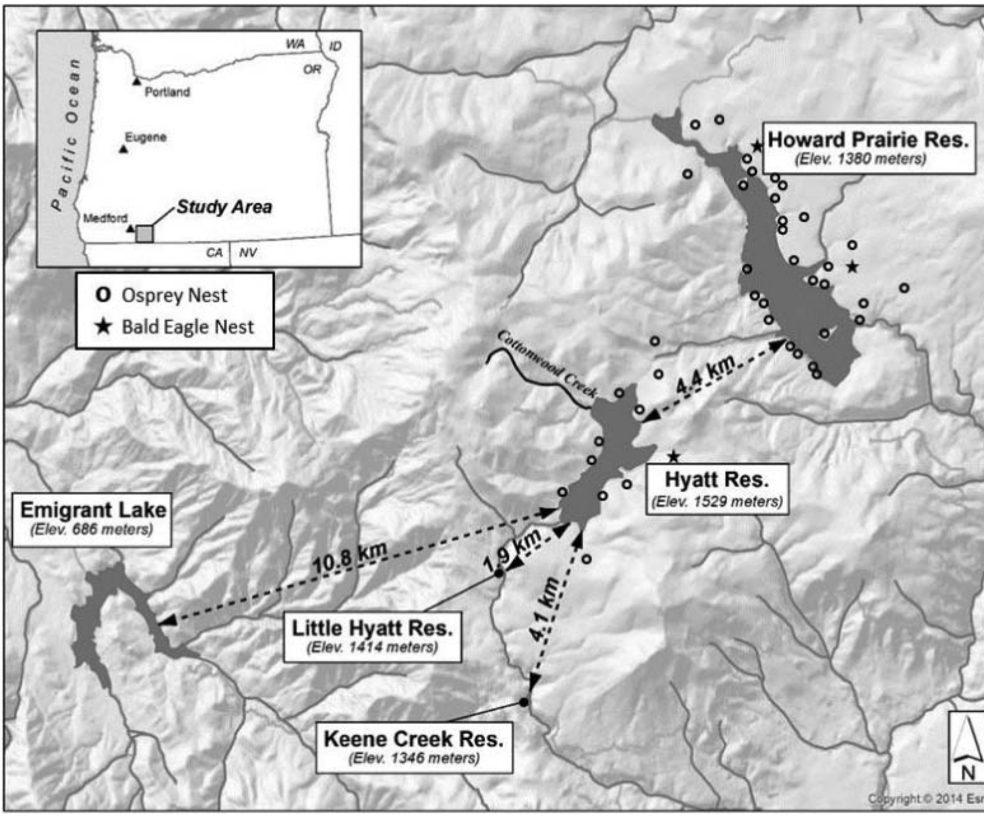

Figure 1. Location of occupied Osprey and Bald Eagle nests in 1990 at Hyatt Reservoir and Howard Prairie Reservoir in southwestern Oregon and relationships to adjacent water bodies.

and popular trout fisheries in Oregon (ODFW 1997).

Experimental Design and Protocol. The field research plan was developed to study the response of the two Osprey populations based upon ODFW's early planning (in 1987) to use rotenone again at Hyatt. Both nesting Osprey populations were studied for 2 yr (1988 and 1989) before the rotenone treatment took place in October 1989 and for 2 yr posttreatment (1990 and 1992).

This comparative field study (treatment vs. reference) provides a basis for evaluating consistency and annual variability in reproductive data collected. Ideally, for an untainted study of possible fish removal effects on a nesting Osprey population, the two Osprey populations studied should be in the same general region, but an adequate distance apart, so that the treatment population could not benefit from fish captured at the reference reservoir, or other nearby water bodies (see Fig. 1). However, this treatment population has several alternative locations to hunt accessible fish at various distances from Hyatt, which probably represents the normal situation for many Osprey nesting populations. Howard Prairie (reference area, 4.4 km away) and Little Hyatt (1.9 km away) were obvious nearby alternative foraging locations. Consequently, Osprey decisions to forage at alternative water bodies would likely minimize any negative effects of rotenone, and therefore, have a positive influence on reproductive parameters recorded during this study. Therefore, we strove to observe foraging flights from Hyatt to other water bodies, and we recorded species and size of fish delivered to nests.

Although Bald Eagles lay eggs earlier in the spring than Ospreys, nesting seasons for both species overlap in Oregon. The presence of nesting Bald Eagles at both reservoirs could influence findings of this study vis-à-vis the long-known trait of eagle piracy of Osprey-caught fish (Bartram 1791, Bent 1937),

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especially when fish prey become greatly reduced. The only nesting Bald Eagle pair at Hyatt received supplemental food provisioning of spawned-out coho salmon (*Oncorhynchus kisutch*) during the 1990 nesting season following rotenone treatment to mitigate potential food loss effects (Kaiser 1990). Eagle reproductive success was recorded, in addition to incidental observations of Bald Eagle-Osprey interactions, and in 1990 piracy rates were recorded during intensive Osprey foraging observations at both reservoirs.

Although our primary interest was to assess the possible effects of the rotenone treatment (food loss) on nesting Ospreys at Hyatt, seasonal or annual changes in water levels at both reservoirs could influence foraging success and potentially reproductive parameters (Johnson et al. 2007, Houston et al. 2010). Likewise, daily weather patterns (precipitation, mean and minimum temperatures), especially cold and wet conditions in May or June, could cause nestling mortality directly or indirectly via reduced prey deliveries and starvation (Reese 1977, Poole 1982, 1989a, Machmer and Ydenberg 1990, De Solla et al. 2003, Johnson et al. 2008, Sivonen 2014). Seasonal changes in water levels (percent of capacity) at both adjacent reservoirs showed similar annual patterns, which eliminated this potentially complicating factor when comparing Osprey reproductive patterns for a given year, but was useful for year-to-year comparisons. Also, daily weather conditions were nearly identical and are not presented here. Monthly reservoir water levels at both reservoirs were recorded by TID, Talent, Oregon (accessed at Hydromet Pacific Northwest, BOR), and daily local weather conditions by PRISM Climate Group, Oregon State University, Corvallis.

Measurement of Productivity. Ground-based nest surveys using binoculars and spotting scopes were generally conducted weekly to record breeding status. Osprey nests ($n = 39$ in 1990; Fig. 1) encircled the two reservoirs and were all built in live (61.5%) or dead (38.5%) trees: Douglas fir (*Pseudotsuga menziesii*) 35.9%, ponderosa pine (*Pinus ponderosa*) 35.9%, and white fir (*Abies concolor*) 28.2%. A special effort was made to count recently hatched nestlings each year at Hyatt, but these counts must be viewed as incomplete because of the difficulty of observing small nestlings in tree-top nests. However, the counts provide a minimum number hatched to compare to the number of near-fledging age young (Henny and Kaiser 2021). Two breeding surveys were conducted by helicopter each year at both reservoirs—the first in mid-May to determine clutch size, the second in mid-July when young were near fledging. A final count of advanced-age young at nests of late nesting pairs was determined from the ground. Nests were classified as active (eggs laid) or occupied (adult pair present) following Osprey reproductive criteria described by Postupalsky (1977). Nests were considered successful if one or more young fledged. The definition of an active nest (also called laying pair by Steenhof and Newton 2007) is more restrictive and excludes territorial pairs that may go through early motions of nest-building (occupied nest). We calculated productivity as the number of advanced-age young per active nest, per occupied nest, and per successful nest.

Observations of Prey Delivery and Foraging. To evaluate factors possibly involved with food shortages, prey deliveries at four active Osprey nests at each reservoir were intensively observed from distant vantage points throughout breeding in 1988, 1990, and 1992 (Henny and Kaiser 2021). Generally, 3-hr observation periods were systematically scheduled each day from dawn to dusk, alternating focal nests and reservoirs to ensure each nest was observed similar amounts of time throughout the day. In 1988 and 1990, observations included other foraging Ospreys in the vicinity of the four intensive nests at each reservoir (while waiting for prey deliveries). These added observations improved sample size to better determine success at capturing fish (success per foraging trip and success per dive) of individual Ospreys (i.e., foraging efficiency and dive success defined by Ueoka and Koplin [1973], Szaro [1978], and Swenson [1979]). On rare occasion, if a nest failed, a neighboring active nest at a similar breeding stage was used as a replacement to ensure a complete data set. All nest and foraging observations were conducted by JLK (sometimes monitoring two active nests simultaneously), except during July 1988 when a second observer assisted. Prey delivery data were grouped into incubation, early nestling, and late nestling periods to evaluate possible food shortages at different stages of the breeding cycle because food requirements increase as young grow (Koplin et al. 1977).

Interval sampling data (10 min) included comments on nest attendance and behavior, number of nestlings, adult male foraging locations, fish prey species (based on shape and color), estimated length of fish delivered to nest (notation if partly eaten by male), food begging, and human or avian nest disturbances. Foraging activities recorded dur-

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ing observation periods included: dive success, estimated fish length, and species captured (bullhead, trout, bass, unknown). Fish length was visually estimated by comparing its length to average length of male Osprey tails (205 mm; MacNamara 1977). Fish length estimates were in 50-mm increments (about one-quarter length of Osprey tails). Fish weight (g) delivered to nest was estimated by length-weight relationships based on metric equations for each species (see Schneider et al. 2000, Table 17.1). For unknowns, we used the mean weight of the three species for a given body length. The number and mass of fish delivered to each Osprey nest was converted to g fish/100 min of observation during the three periods of the nesting cycle, and finally to number and g of fish delivered to each nest in a day. Average day length in May (877 min, incubation period), June (916 min, early nestling), and July (897 min, late nestling) was obtained for nearby Medford, Oregon, and used to convert values/100 min to values/d, based on systematic nest observation periods throughout the study. The number fledged at each intensively observed nest in 1990 at Hyatt was evaluated (ranked) in relation to bullhead numbers (none in Hyatt) brought to that nest.

RESULTS

Hyatt Reservoir 1988–1990: Fish Availability, Natural Fish Die-off, Rotenone Fish Kill, and Restocking. Bullheads were especially vulnerable to Ospreys when higher water temperatures and low water levels created aquatic hypoxia conditions causing them to regularly "gulp" air at the surface. However, when reservoir volume decreased to 25–35% of capacity during July–August and cyanobacteria (blue green algae blooms) severely decreased water clarity, Osprey shifted foraging to Little Hyatt, soon returning with fish (primarily bullheads) throughout the remainder of the 1988 and 1989 nesting seasons. Similar flights were made to Little Hyatt in early summer 1990, 2 mo after Hyatt was restocked with trout/steelhead, which quickly dispersed throughout the reservoir toward underwater cover, and dramatically reduced foraging success and presented another food shortage for Osprey. Thus, fish availability for foraging Ospreys at Hyatt was dynamic and ever-changing throughout the study (including pretreatment years).

A natural die-off of stunted bullheads occurred at Hyatt about 15 May 1989 when shore length was 10,058 m. On 31 July, we established 0.914-m wide sampling units at approximately 150 m intervals (67 sampling units) around the entire reservoir to count dead fish. An estimated 1,058,955 fish floated to shore.

Before the rotenone application on 12 October 1989, Hyatt was partially drained. Liquid rotenone was applied by hand and boat to a concentration of 2.5 parts per million. Shore length at the time was estimated at 8500 m and the same dead fish sampling procedure was followed on 19 October. An estimated 995,100 dead fish floated to shore within 1 wk of rotenone treatment. An additional 43,500 bullheads were collected by locals for human consumption (ODFW unpubl. data), making an estimated total of 1,038,600 fish floating to shore. Based on Bradbury (1986) and Parker (1970), we estimated this represented approximately 30% of fish killed; thus, the estimated numbers of fish removed from Hyatt via the natural die-off in May 1989 and the rotenone treatment in October 1989 were adjusted upward to an estimated 3,530,000 and 3,462,000, respectively.

Gill net sampling by ODFW at Hyatt in the spring and fall of 1990 yielded no bullheads. Hyatt was stocked on 23 and 25 April 1990 with nearly equal numbers (10,013 and 11,220) of yearling steelhead and trout (generally 200–250 mm), and a few mature trout (up to 460 mm; Table 1). The reservoir was also stocked on 11 May with an additional 250,125 fingerling trout (75–130 mm), which grow to approximately 254 mm by the following spring, and nearly 15,000 fingerling bass on 15 August (ODFW 1997). A local bass club also introduced 48 bass of various sizes from nearby Emigrant Lake on 17 August (D. Haight, ODFW, pers. comm.). Invertebrate prey for hatchery fish released at Hyatt in spring 1990 was likely adequate (Linn 2002), resulting in normal post-release fish movements and dispersal.

Pretreatment: Osprey Populations and Reproductive Success. Numbers of nesting Osprey pairs and their reproductive rates were consistent in many respects at Hyatt and Howard Prairie (treatment vs. reference) in 1988 and 1989 prior to rotenone treatment (Table 2). Furthermore, the percentage of active nests fledging two or three young (no nests with four young) in 1988–1989 was similar at both reservoirs (69% vs. 63%). In 1989, even with a loss of about 50% of the bullhead population (from approximately 7 million to approximately 3.5 million following the natural die-off about 15 May), the number of occupied Osprey nests and reproductive rates at Hyatt in 1989 were not

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Table 1. Fish stocking records for rainbow trout, winter and summer steelhead (fork length), and largemouth bass (total length); and date of release at Hyatt Reservoir, Little Hyatt Reservoir, and Howard Prairie Reservoir, Oregon, 1988–1992. Data source: ODFW release records, May 2017.

Site	Year	Date	Species	Number	Size[a]
Hyatt Reservoir	1988	None	None	None	None
	1989	14 Apr	Rainbow	2054	yearling
	1989	9 May	Rainbow	3495	yearling
	1989	9 May	W. steelhead	9528	yearling
	1989	25 May	Rainbow	5088	yearling
	1989	16 Jun	Rainbow	2635	yearling
	1990	23 Apr	W. steelhead	10,013	yearling
	1990	25 Apr	Rainbow	11,220	yearling
	1990	11 May	Rainbow	250,125	fingerling
	1990	15 Aug	Largemouth bass	14,992	fingerling
	1990	17 Aug	Largemouth bass	48[b]	various
	1991	29 May	Rainbow	250,240	fingerling
	1991	26 Jun	Rainbow	5978	yearling
	1991	12 Nov	S. steelhead	26,668	fingerling+
	1991	12 Nov	W. steelhead	13,224	fingerling
	1991	22 Nov	Rainbow	5029	fingerling+
	1992	5 Jun	Rainbow	1409	yearling
Little Hyatt Reservoir	1988	9 May	Rainbow	2500	fingerling
	1989	9 May	Rainbow	2500	fingerling
	1990	29 May	Rainbow	2520	fingerling
	1991	12 Jun	Rainbow	2432	fingerling
	1992	18 May	Rainbow	100,143	fingerling
	1992	8 Jun	Rainbow	4498	fingerling
Howard Prairie Reservoir	1988	9 May	Rainbow	350,840	fingerling
	1988	10 May	Rainbow	52,000	fingerling
	1989	30 May	Rainbow	350,588	fingerling
	1990	30 May	Rainbow	351,030	fingerling
	1990	30 Oct	Rainbow	4368	fingerling+
	1991	29 May	Rainbow	376,830	fingerling
	1992	18 May	Rainbow	250,707	fingerling

[a] Size: yearling (200–250 mm), fingerling (75–130 mm), fingerling+ (100–180 mm).
[b] Bass club released: Largemouth bass (150–380 mm).

adversely affected. Similarities of pretreatment Osprey data obtained during these 2 yr further justified the selection of Howard Prairie as a reference site. No foraging trips by Ospreys to Howard Prairie from Hyatt were observed during the pretreatment years.

First Breeding Season After Rotenone Treatment: Osprey Populations and Reproductive Success. The first Osprey at Hyatt in 1990 was observed on 20 March, when only a small portion of the reservoir was ice-free. By 22 March, Hyatt was only half ice-covered, and by 25 March Osprey were present at four nests. Other Ospreys returned to Hyatt in late March–early April 1990 (prior to ODFW restocking fish on 23 and 25 April).

Upon arrival at Hyatt, Ospreys endlessly searched the fishless reservoir until restocking occurred. Foraging observations at Hyatt (11 d, 40.25 hr) indicated Ospreys only flew toward or returned from Howard Prairie with fish on four occasions during 1–23 April (before Hyatt was restocked). Foraging flights from Hyatt toward Little Hyatt or lower-elevation water bodies also yielded few observations of fish brought back from that direction. On 5 April, an Osprey pair nesting near Cottonwood Creek at the northwestern corner of Hyatt was twice observed feeding on trout (200 mm and 400 mm), perhaps captured from that creek. A dominant red lateral line on the captured fish suggested indigenous redband trout (*Oncorhynchus mykiss gairdnerii*) or perhaps a survivor from the 9528 yearling steelhead

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Table 2. Osprey reproductive parameters, Hyatt Reservoir (387 ha) and Howard Prairie Reservoir (805 ha), Oregon, 1988, 1989, 1990, and 1992.

		Pretreatment Years		Posttreatment Years	
Site	Reproductive Parameter	1988	1989	1990	1992
Hyatt Reservoir	Occupied nests	10	10	10	11
	Active nests (% of occupied)	8 (80)	8 (80)	10 (100)	9 (82)
	0 fledged	1	0	1	1
	1 fledged	1	3	7	5
	2 fledged	4	3	2	2
	3 fledged	2	2	0	1
	Mean clutch size (n)[a]	2.86 (7)	2.66 (6)	2.55 (9)	2.28 (7)
	Successful nests[b] (% of occupied)	7 (70)	8 (80)	9 (90)	8 (73)
	Minimum no. eggs hatched	17	15	16	12
	No. of fledglings	15	15	11	12
	Productivity, young/occupied nest	1.50	1.50	1.10	1.09
	Productivity, young/active nest	1.88	1.88	1.10	1.33
	Productivity, young/successful nest	2.14	1.88	1.22	1.50
Howard Prairie Reservoir (reference)	Occupied nests	27	27	29	25
	Active nests (% of occupied)	25 (93)	24 (89)	29 (100)	23 (92)
	0 fledged	7	5	3	7
	1 fledged	2	4	4	4
	2 fledged	10	10	10	8
	3 fledged	6	5	12	4
	Mean clutch size (n)[a]	2.94 (17)	2.53 (19)	2.82 (22)	2.19 (16)
	Successful nests[b] (% of occupied)	18 (67)	19 (70)	26 (90)	16 (64)
	No. of fledglings	40	39	60	32
	Productivity, young/occupied nest	1.48	1.44	2.07	1.28
	Productivity, young/active nest	1.60	1.63	2.07	1.39
	Productivity, young/successful nest	2.22	2.05	2.31	2.00

[a] (n) number nests with eggs counted.
[b] Fledged at least one young.

released into Hyatt on 9 May 1989 that may have moved up the principal tributary before the rotenone application. On 11–13 April, four Ospreys were observed searching Hyatt for fish before departing south over the dam toward Little Hyatt then further toward Emigrant Lake in the valley below. No Osprey were observed at Little Hyatt immediately after foraging flights in that direction. On 13 April, the same nest pair near Cottonwood Creek was observed eating a live 600-mm trout; on 20 April, another male returned to its nest at the south end of the reservoir with a 150–200 mm trout (less head).

All 10 nests at Hyatt were occupied by 23 April 1990 (restocking day), with incubation occurring at five nests. Yearling hatchery trout and steelhead (200–250 mm) were released into the reservoir at dusk. The following day three Hyatt Osprey males caught fish on their first dive at dawn near the boat ramp where fish were released. Hyatt Ospreys regularly caught fish near the release site until approximately 1 wk later when fish dispersed throughout the reservoir. Van Daele and Van Daele (1982) noted that hatchery-reared trout are unfamiliar with their new surroundings and therefore vulnerable to predation, and fish injured during the stocking process likely form a part of the Ospreys' catch. On 30 April, several Hyatt Ospreys again discovered a few steelhead in the small pools of Cottonwood Creek within 1 km of Hyatt and regularly foraged there (30 April–9 May), capturing a few fish. During the remainder of the spring and summer, Ospreys had difficulty capturing fish at Hyatt despite stocking of an additional 250,125 fingerling trout on 11 May (see Foraging Efficiency). They resumed flights in search of prey toward adjacent water bodies, primarily following the Hyatt Dam outflow toward Little Hyatt, and further down the mountain toward Keene Creek Reservoir and Emigrant Lake where Ospreys had not established nest sites.

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In 1990, the number of occupied nests at Hyatt remained unchanged at 10, and at Howard Prairie increased by two to 29 (+7.4%; Table 2). The 15 fledglings produced each pretreatment year at Hyatt declined to 11 fledglings in 1990. Although ground-based hatch counts at Hyatt were probably incomplete, the minimal extent of brood reduction at Hyatt in 1990 (16 hatched, 11 fledged, –31%) compared poorly with both pretreatment years combined when only two nestlings failed to fledge (32 hatched, 30 fledged, –6%). Hyatt productivity rates (young fledged/occupied nest and young fledged/active nest) were extremely high and identical in 1988 and 1989, but decreased in 1990 following rotenone treatment (Table 2). Likewise, the number of young fledged/successful nest over time at Hyatt followed the same pattern. Brood reduction at Hyatt was confirmed by 7 July (young < 4 wk old) when 10 nests contained only 13 young, with two young dying later. The five earliest laying pairs at Hyatt in 1990 that fledged seven young (1.40) were likely more experienced breeders; however, the nest sites of the two pairs that each fledged two young were located at the extreme north and south ends of the reservoir (closest to adjacent fishable waters). The five pairs that bred later fledged only four young total (0.80).

At Howard Prairie the number of occupied and active nests remained consistent for the first 3 yr of the study. Productivity rates (young/occupied nest, young/active nest) were also similar in 1988 and 1989, but then, in contrast to Hyatt, improved at Howard Prairie in 1990 (Table 2). Ospreys at Howard Prairie consistently fledged broods of two and three young in 1988, 1989, and 1990, i.e., much like production at Hyatt in 1988 and 1989 before treatment. Then in 1990, only 20% of the active nests at Hyatt fledged two young, while none (0%) fledged three. This contrasts with nearby Howard Prairie in 1990 where productivity remained excellent (34% fledged broods of two and 41% fledged broods of three; Table 2).

Third Year Posttreatment: Osprey Populations and Reproductive Success. Reproductive rates (young/occupied nest, young/active nest) in 1992 were below pretreatment rates at both Hyatt and Howard Prairie (Table 2). At Hyatt in 1992, the numbers of occupied nests, active nests, and successful nests were at or above pretreatment numbers, while the overall number of fledglings produced was down slightly from pretreatment numbers (15, 15 vs. 12). At Howard Prairie in 1992, occupied nests, active nests, and successful nests were down slightly from pretreatment numbers, but as at Hyatt, fewer young were fledged (40, 39 vs. 32), i.e., number fledged in 1992 decreased at Hyatt by 20% and at Howard Prairie by 19%. It is perhaps noteworthy that drought conditions occurred at both reservoirs in 1992, with reservoir volume showing no increase in April or May, but instead a steady decline through August (Fig. 2).

Foraging Efficiency, Prey Delivery Rates, Fish Size and Species Captured in 1988, 1990, and 1992. Osprey foraging efficiency (percent foraging bouts successful) at Hyatt in 1988 (94.3%) and Howard Prairie in 1988 (96.4%) and 1990 (92.7%) was very high, with fish often caught on the first dive (Table 3). Following rotenone treatment and fish restocking at Hyatt in 1990, only 49.0% of the foraging bouts were successful. A similar pattern was observed when comparing success rates of individual dives in 1988 vs. 1990 at Hyatt (75.9% vs. 33.3%) and at Howard Prairie (74.3% vs. 70.3%). Foraging efficiency and dive success rates provided useful information for a comparative evaluation of suitable prey availability between reservoirs and years once prey were located; however, daily fish delivery rates (including estimated fish weight) to specific nests per day is considered a more useful measure of food availability when evaluating productivity responses (Koplin et al. 1977).

ODFW personnel routinely used gill nets in the fall (September–November) of 1987–1992 (including years of this study) to monitor size (not numbers) of trout and bullheads at both Hyatt and Howard Prairie and sometimes Little Hyatt. Bullheads (principal prey species at both reservoirs) captured in gillnets by ODFW at Hyatt in 1987, 1988, and 1989 averaged shorter (166, 179, and 204 mm) than those captured at Howard Prairie the same years (208, 231, and 236 mm) by 20.1, 22.5, and 13.6% (Table 4). The apparent increase in length of bullheads at Hyatt in 1989 was likely the result of the natural die-off of 3.5 million bullheads that reduced competition 5 mo before samples were collected on 13 October 1989 following rotenone treatment.

We evaluated both fish weight and fish numbers delivered to specific nests per day. Prey deliveries were observed at four Osprey nests at each reservoir throughout the nesting cycle (incubation, early nestling, and late nestling stages; Table 5). The four nests at Hyatt fledged seven young in 1988, five in 1990, and five in 1992. The number of fish delivered to Hyatt nests per day was less in 1990 than in 1988

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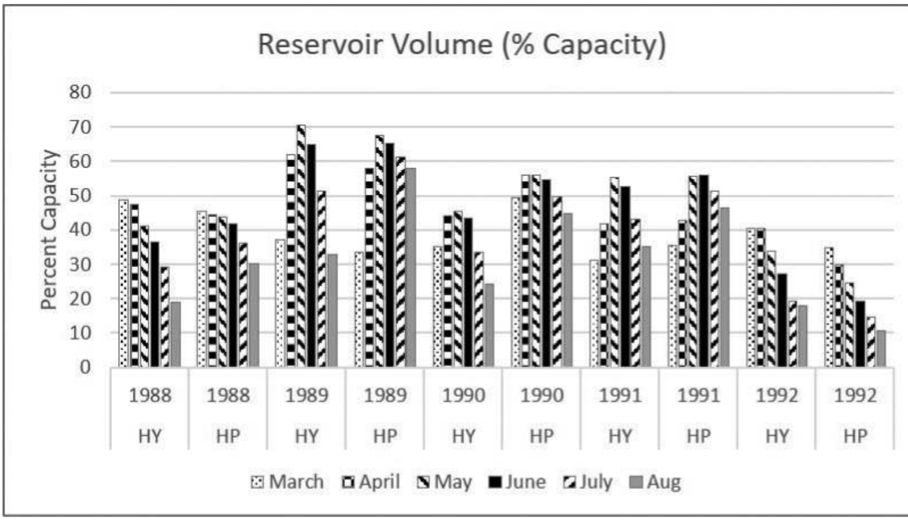

Figure 2. Monthly reservoir volume (percent capacity) at Hyatt (HY) and Howard Prairie (HP) Reservoirs during the Osprey nesting season, 1988–1992. Data Source: Hydromet Pacific Northwest, US Bureau of Reclamation, http://www.usbr.gov/pn/hydromet.

for all nesting stages: incubation (–48%), early nestling (–39%), and late nestling (–50%). Estimated mass of fish delivered (g/d) also decreased in 1990 compared to 1988 at Hyatt, with the observed differences dependent upon fish weight: incubation (–73%), early nestling (–62%), and late nestling (–37%). Smaller hatchery fish were caught in 1990 during incubation and early nestling stages. No bullheads were delivered to the four Hyatt nests during incubation and early nestling observation periods; however, larger bullheads from adjacent waters (primarily Little Hyatt) were delivered during the late nestling period in 1990. The number and mass of fish delivered per d in 1992 at Hyatt remained below values recorded pretreatment (1988).

Fish species delivered to the four focal Hyatt nests during the three stages of the nesting season in 1988 ($n = 99$) were primarily bullheads (74.7%), followed by trout (11.1%), bass (4.0%), and 10.1% unknowns

Table 3. Foraging parameters for Ospreys that dove, Hyatt Reservoir and Howard Prairie Reservoir, Oregon, 1988 and 1990.

	HYATT RESERVOIR		HOWARD PRAIRIE RESERVOIR	
FORAGING PARAMETER	1988	1990	1988	1990
No. dive attempts observed	87	72	218	108
No. successful dives (%)	66 (75.9%)	24 (33.3%)	162 (74.3%)	76 (70.3%)
Successful Ospreys requiring				
1 dive	56	21	138	58
2 dives	8	2	19	12
3 dives	1	0	4	6
4+ dives	1	1	1	0
Successful Ospreys	66; 80 (94.3%)[a]	24; 32 (49.0%)[a]	162; 193 (96.4%)[a]	76; 100 (92.7%)[a]
Unsuccessful Ospreys	4; 7 (5.7%)[b]	25; 40 (51.0%)[b]	6; 25 (3.6%)[b]	6; 8 (7.3%)[b]
Total no. Ospreys diving	70	49	168	82
Hours observed[c]	123	133	187	96

[a] Ospreys successful, number of dives, (percent of all Ospreys successful).
[b] Ospreys unsuccessful, number of dives, (percent of all Ospreys unsuccessful)
[c] Hours based on intensive nest observation periods, but include additional observations of Ospreys foraging in vicinity.

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Table 4. Mean length and weight of rainbow trout (fork length) and brown bullheads (total length) collected by ODFW and others at Hyatt Reservoir, Howard Prairie Reservoir, and Little Hyatt Reservoir, 1987–1992. Note: Gillnet captures (usually three sets) in the fall (September–November), with four exceptions noted. Brown bullheads were seldom weighed and rainbow trout were not all weighed at some locations and years (data used only when all were weighed). Pumpkinseeds and golden shiners (generally 100–180 mm) were also captured in gillnets from 1987–1992.

	Rainbow Trout									Brown Bullhead							
	Hyatt			Howard Prairie			Little Hyatt			Hyatt			Howard Prairie			Little Hyatt	
Year	n	Length (mm)	Wt. (g)	n	Length (mm)	Wt. (g)	n	Length (mm)	Wt. (g)	n	Length (mm)	Wt. (g)	n	Length (mm)	Wt. (g)	n	Length (mm)
1987	112	246	–	60	284	–	13	236	–	125	166	–	85	208	–	32	204
1988	43[a]	275	230	108	292	–	–	–	–	141	179	–	58	231	–	–	–
1988[b]	10	276	199	28	377	582	3	320	290	71	186	86	71	243	201	–	–
1989	22	280	251	15	268	356	–	–	–	73[c]	204	101	20	236	–	–	–
1990	45	309	439	116	290	362	23	230	155	–	–	–	–	–	–	–	–
1991	11	346	680	216	236	–	26	227	156	–	–	–	11	230	–	50	177[d]
1992	35	280	393	190	230	–	31	197	95	–	–	–	41	221	–	5	212

[a] Caught in gillnets 5 May and 2 June 1988.
[b] Caught by anglers (who sometimes release smaller fish) 22 June to 7 August 1988.
[c] Bullheads collected 13 October 1989 (1 d after rotenone treatment).
[d] Caught 399 in trap net 4 June 1991 (6 d set).

(Table 5). Prey species composition changed dramatically in 1990 with trout the dominant prey species during incubation (90% trout and 10% unknown) and early nestling (76.2% trout, 23.8% unknown). Some yearling trout/steelhead released into Hyatt on 23 and 25 April 1990 provided a very brief foraging opportunity near the release site until the trout/steelhead dispersed throughout Hyatt. However, some steelhead were soon discovered and captured at Cottonwood Creek by Hyatt Ospreys nesting nearby. The first bullheads delivered to Hyatt nests occurred during the late nestling period (29.4% bullheads, 35.3% trout, 35.3% unknown). With no bullheads in Hyatt in 1990, the bullheads were primarily caught at Little Hyatt, with some likely captured at Howard Prairie. Ospreys from three of the four nests studied in detail at Hyatt in 1990 often returned with 175–275 mm bullheads during the summer. Only one of the four intensively observed pairs at Hyatt in 1990 fledged two young, and that nest had the most bullheads delivered during our observation periods.

Fish deliveries during the nesting cycle at Hyatt in 1992 (no incubation data; early and late nestling combined) included trout/steelhead (68.9%), bass (22.2%), and unknowns (8.9%), but no identified bullheads.

Nesting Bald Eagles. One pair of Bald Eagles nested each year at Hyatt from 1988 to 1992 and fledged five young in that time. At larger Howard Prairie one pair nested in 1988 and 1989, and two pairs in 1990, 1991, and 1992 (Isaacs and Anthony 1994). Following rotenone treatment, eagle incubation at Hyatt was first observed on 4 March 1990, with hatching on 6 April, and one young fledged in early July. The number of young fledged per occupied nest during this study was similar at both reservoirs and averaged 1.00 at Hyatt, and 1.13 at Howard Prairie. During 1990, 1991, and 1992 when two pairs nested at Howard Prairie, eagle nesting density was 1.24 pairs/500 ha water, and at Hyatt a nearly identical 1.29 pairs/500 ha. Also, occupied Osprey nests at both locations showed similar densities during this study (Table 2): Hyatt 13.24 pairs/500 ha, and Howard Prairie 16.77 pairs/500 ha.

With fewer fish available at Hyatt posttreatment, Bald Eagle piracy of fish captured by Ospreys was expected to increase and have a negative influence on Osprey prey delivery rates. Analysis of eagle piracy observations at both reservoirs in 1990 suggest that provisioning of supplemental food for nesting eagles at Hyatt lowered piracy rates. During our observations throughout the nesting cycle at four Osprey nests at Hyatt and at Howard Prairie in 1990, a higher percentage of fish captured at Howard Prairie (21.3%) were pirated compared to Hyatt (6.1%; $\chi^2_1 = 4.706$, $P = 0.030$, Table 6). Thus, the Bald Eagle pair at Hyatt, supplemented with salmon carcasses in 1990, likely played a minor role in the depressed Osprey reproductive success that year.

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Table 5. Prey delivery rates through the nesting cycle, including fish species and size, based on observations at four Hyatt Reservoir and four Howard Prairie Reservoir Osprey nests in 1988, 1990, and 1992. nd = no data.

	Prey Delivery Rates by Location and Year					
	Hyatt Reservoir			Howard Prairie Reservoir		
Period and Delivery Metric	1988	1990	1992	1988	1990	1992
Incubation period (May)						
Min obs. (no. fish delivered)	2700 (13)	4035 (10)	nd	3060 (12)	2520 (5)	nd
No. fish/100 min (fish/d)	0.481 (4.22)	0.248 (2.18)	nd	0.392 (3.44)	0.198 (1.74)	nd
G fish/100 min (g fish/d)	45.89 (402.5)	12.19 (107.0)	nd	56.13 (435.0)	27.99 (245.5)	nd
Mean length (mm)	182.7	170.9	nd	183.6	170.0	nd
Mean weight (g)	95.30	49.20	nd	126.48	90.02	nd
Fish species composition						
Brown bullhead	76.9%	0%	nd	50.0%	80.0%	nd
Rainbow trout	7.7%	90.0%[a]	nd	8.3%	0%	nd
Largemouth bass	0%	0%	nd	0%	0%	nd
Unknown	15.4%	10.0%	nd	41.7%	20.0%	nd
Early nestling period (June)						
Min obs. (no. fish delivered)	2720 (20)	4680 (21)	3180 (20)	2160 (13)	4140 (19)	nd
No. fish/100 min (fish/d)	0.735 (6.73)	0.449 (4.11)	0.629 (5.76)	0.602 (5.51)	0.459 (4.20)	nd
G fish/100 min (g fish/d)	101.35 (928.4)	38.37 (351.5)	59.13 (541.5)	58.23 (533.4)	66.08 (605.3)	nd
Mean length (mm)	211.8	190.4	177.6	192.3	205.9	nd
Mean weight (g)	137.83	85.52	94.01	96.75	143.97	nd
Fish species composition						
Brown bullhead	70.0%	0%	0%	61.5%	41.2%	nd
Rainbow trout	10.0%	76.2%[a]	95.0%	0%	26.3%	nd
Largemouth bass	5.0%	0%	0%	0%	0%	nd
Unknown	15.0%	23.8%	5.0%	38.5%	31.6%	nd
Late nestling period (July)						
Min obs. (no. fish delivered)	6680 (66)	3450 (17)	3720 (25)	5280 (44)	3600 (23)	3600 (23)
No. Fish/100 min (fish/d)	0.988 (8.86)	0.493 (4.42)	0.672 (6.03)	0.833 (7.48)	0.639 (5.73)	0.639 (5.73)
G fish/100 min (g fish/d)	131.22 (1177.1)	82.56 (740.6)	62.06 (420.9)	98.98 (888.8)	97.74 (876.7)	94.96 (851.9)
Mean length (mm)	197.8	228.2	188.8	200.0	215.9	222.8
Mean weight (g)	132.81	167.55	92.29	118.77	153.20	148.63
Fish species composition						
Brown bullhead	75.8%	29.4%	0%	79.5%	91.3%	43.5%
Rainbow trout	12.1%	35.3%[a]	48.0%	9.1%	4.3%	52.2%
Largemouth bass	4.5%	0%	40.0%	2.3%	0%	0%
Unknown	7.6%	35.3%	12.0%	9.1%	4.3%	4.3%

[a] Includes winter steelhead (200–250 mm) stocked 9 May 1989 and 23 April 1990; estimated growth rate = 25 mm/mo.

Table 6. Fish caught by Ospreys at four intensively observed nests in 1990 and piracy rates by Bald Eagles at Hyatt Reservoir and Howard Prairie Reservoir. Total observation time: Hyatt 203 hr; Howard Prairie 171 hr.

	Hyatt Reservoir		Howard Prairie Reservoir	
Time Period	Fish Caught	Eagle Robbed	Fish Caught	Eagle Robbed
Incubation	10	1 (10.0%)	5	2 (40.0%)
Early nestling	22	2 (9.1%)	19	4 (21.1%)
Late nestling	17	0 (0%)	23	4 (17.4%)
Totals	**49**	**3 (6.1%)**	**47**	**10 (21.3%)**

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With a continued stable bullhead population at Howard Prairie and large numbers of trout fingerlings released annually, the Osprey productivity remained extremely high in 1990, irrespective of the seemingly frequent Bald Eagle robbery rate.

Discussion

Newton (1998) noted for raptors that it is "beyond question" that food shortages can affect individuals directly, through causing breeding failure or starvation. Prey availability influences reproductive success because the pre-breeding condition of the female raptor determines its ability to produce young, and because food must be available not only for the adults, but also for the young (Newton 1979). Lack of food at various points in the breeding cycle may inhibit nesting attempts, cause abandonment of the nesting effort, or result in starvation of young. Newton (1979) recognized three levels of response to annual changes in prey numbers: (1) populations subject to the most marked prey cycles show big local fluctuations in nesting densities and breeding rates, (2) populations subject to less marked prey cycles show fairly stable densities, but big fluctuations in breeding rates, and (3) populations with stable prey numbers show stable densities and fairly stable breeding rates. He further noted that raptors with stable food supplies show some of the most extreme stability in breeding populations recorded in birds, with numbers varying by no more than 15% of the mean over several decades.

Observed Osprey productivity rates at both Hyatt and Howard Prairie during the two pretreatment years (1988–1989) were similar (1.88 and 1.61 advanced-age young /active nest) and well above the perceived recruitment standard of 0.8 to 0.9 young/active nest, but perhaps slightly higher for some populations (Poole et al. 2002). This pretreatment reproductive rate implies there were no potentially confounding other contaminant-related issues. Ospreys were primarily feeding on bullheads with some trout at both Hyatt and Howard Prairie during the pretreatment period. Vana-Miller (1987) reported that the abundance and availability of a given fish species determines what Ospreys capture, and only two or three of all available fish species predominate in their diet at any specific location. Prior to rotenone treatment, both reservoirs provided optimum nesting habitat with an abundance of prey.

As anticipated, this study provided a unique opportunity to determine if food limits reproductive success in Ospreys, and if so, at what stage. Osprey pairs remained at the reservoir and laid eggs which, as Newton (1979) indicated, was typical for a species that normally relies on stable prey numbers. In fact, the number of occupied, active, and successful nests at Hyatt in 1990 remained at or above numbers reported for 1988 and 1989. Furthermore, numbers of recently hatched nestlings (although minimum counts) were similar in 1990 (16) to numbers in 1988 and 1989 (17 and 15) and in agreement with Eriksson's (1986) finding of no relationship between fish biomass delivered per day and number of hatched young in Sweden. The reduction in young fledged at Hyatt (only 11) was the result of more nestling mortality including immediately prior to fledging in 1990 (31%) than in 1988–1989 (6%). Similarly, Eriksson (1986) reported the daily amount of fish delivered was lower among nests where nestlings died before fledging. These findings indicated that the nestling stage was the critical period when reduced food availability and lower provisioning rates exerted their negative influence on Osprey productivity (Table 2).

Other published nestling loss (pre-fledge mortality) rates for Osprey include an 8% loss during a 2-yr study (1983–1984) in Sweden (Eriksson 1986) and a 10% loss during a 2-yr study (1987–1988) in British Columbia, Canada (Steeger et al. 1992). A 5-yr study (1970–1974) in Chesapeake Bay, USA, reported annual nestling mortality of 12%, 19%, 23%, 8%, and 15% (Reese 1977), while a 4-yr study in New England, USA, reported similar (10–20%) nestling mortality, with 75% of the deaths attributed to starvation (Poole 1984). Our high loss rate at Hyatt in 1990 (minimum 31%) was surpassed by nestling mortality rates of 45% and 43% in 1983 and 1984 at Lake Ellis Simon, North Carolina, USA (Hagan 1986, J. Hagan pers. comm.). The Lake Ellis Simon food shortage was thought to be related to the long distances to Osprey foraging areas (26-km round trip) which negatively influenced food delivery. The nestling mortality in North Carolina occurred primarily at age 2–3 wk (i.e., steep phase of logistic growth curve, with none after 45 d; Hagan 1986). Brood reduction was confirmed at <4 wk in our Hyatt study in 1990. It is notable that many intraspecific agonistic encounters observed at Hyatt in 1990 involved foraging Ospreys chasing others from preferred feeding areas or attempting to steal recently caught fish from others at the same foraging sites. This uncommon territorial behavior and attempted fish piracy throughout the nesting season likely resulted from the unpredictable fish-prey

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resource in 1990 in combination with a relatively dense nesting population. This finding contrasts with reports of an absence of foraging territoriality at coastal sites, where Ospreys breed in loose colonies (Greene and Freedman 1986, Poole 1989b, Edwards 1989), and our observations of Osprey foraging behavior at Hyatt in 1988 and 1989 when prey were abundant.

Following the rotenone treatment, 10 Hyatt Osprey nests produced 1.10 young/active nest in 1990, which was close to the 0.93 and 1.02 young/active nest produced at Lake Ellis Simon in 1983 and 1984 (Hagan 1986). Only 3 of 82 active nests (4%) at Lake Ellis Simon fledged three young, despite 30 nests with an initial brood size of three (i.e., 90 young hatched, but 46 [51%] died before fledging). At Hyatt in 1988–1989 (pre-rotenone), 4 of 16 active nests (25%) fledged three young, but in 1990 no nests fledged three young (Table 2). The two Hyatt nests that each fledged two young in 1990 included one nest we observed intensively. The male at this nest delivered the most bullheads (none from Hyatt) to its nest when bullheads became active as water temperatures warmed in the summer, i.e., an additional clue to importance of bullheads from adjacent food sources. An Osprey population nesting in Long Valley, Idaho, USA (50 nesting pairs) routinely flew up to 10 km from nest sites to Cascade Reservoir to catch brown bullheads, the prominent prey species in their diet, and only known bullheads in the area (Van Daele and Van Daele 1982). Without fish obtained from adjacent waters, fledging rates at Hyatt would likely have fallen below the population maintenance level. Under existing conditions at Hyatt in 1990 brood size was reduced, but the population still fledged an adequate number of young to maintain a stable population. Nestlings compete with one another when prey is delivered at an insufficient rate (Poole 1982, Jamieson et al. 1983, Hagan 1986, Steidl and Griffin 1991). However, because of asynchronous hatching, brood size reduction is minimized. If enough food is being provided to support only one young, the first-hatched will dominate and survive. Brood reduction is an adaptive mechanism by which birds adjust the optimal brood size (in a specific season) to fluctuations in the food supply and/or the environment.

Osprey dive success was extremely high at both reservoirs in 1988, but only remained high at the non-treated reference reservoir in 1990. Fewer catchable fish were available at posttreatment Hyatt in 1990 and species composition of prey fish changed dramatically from bullheads to primarily hatchery-reared trout/steelhead. Swenson (1979) reported that Osprey dive success ranged from 91% down to 19% in 13 Osprey foraging studies and that a "prey species foraging index" (i.e., an index that distinguishes slow-moving benthic vs. fast-moving piscivorous fish) accounted for 74% of the observed variation in dive success. When trout were an important part of the diet (the situation in many western states), dive success ranged from 47 to 58%, much lower than the Ospreys' high pretreatment success (75.9 and 74.3%) at the two reservoirs where bullheads, with their sluggish behavior in shallow water, were easy to catch. Thus, the lower reproductive success at Hyatt in 1990, associated with reduced dive success (33.3%), was partially attributable to the change in fish species captured (from primarily bullheads to trout/steelhead), but also a function of the lower fish abundance (stocked numbers in Table 1 vs. millions of bullheads).

In addition to reduced dive success posttreatment, fewer fish and a lower mass of fish were delivered to nests at Hyatt in 1990 vs. 1988. Differences between numbers and grams of fish delivered were due to fish size, i.e., stocked fish weighed less early, but larger bullheads (and trout) captured at other locations later in season were most important when nestling growth and corresponding food requirements increased. Using a model developed by Wiens and Innis (1974), Lind (1976) calculated that adult Ospreys require 286 kcal/d, nestlings 11 and 16 d old need 113 and 170 kcal/d, respectively, and fledglings need 254 kcal/d. Based on a fish energy density of 1 kcal/g body weight (Winberg 1960), a nest with two young and one adult (males rarely ate at nest) requires 794 g of fish/d at fledging time, and a nest with three young requires 1048 g/d. Poole (1982) reported male Ospreys delivered to nests with young from Eastern Long Island, New York, Gardiner's Island, New York, and Florida Bay, Florida, USA, the following: 1426 g/d, 915 g/d, and 816 g/d, respectively. The highest incidence of three or four young fledged (15% in 1978 and 36% in 1979) occurred at Eastern Long Island where the highest daily food delivery rate occurred (1426 g). At Poole's two other locations, the incidence of three or four fledged ranged from 0 to 10%. At the pretreatment Hyatt Reservoir in 1988, 928 and 1177 g/d were delivered to the nest during the early and late nestling stages (Table 5) and 25% of nests fledged three young (Table 2). However, at post-treatment Hyatt Reservoir in 1990, food delivery

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(352 and 741 g/d, early and late nestling stages) was below maintenance estimates and below that observed by Poole for Florida Bay and Gardiner's Island and resulted in no nests fledging three or more young.

Overall, we found no reduction in nesting Osprey numbers (occupied or active nests); however, reproductive rates (based on occupied, active, and successful nests) following rotenone treatment in 1990 decreased only at Hyatt. This 1990 decrease (41.5% for young fledged/active nest) from essentially optimum production in 1988 and 1989 was associated with a change in fish species composition, fish numbers present, and an associated reduction in dive success at Hyatt and prey delivery to the nests.

During the 1988 and 1989 pretreatment years, when water transparency was sometimes poor at Hyatt, Osprey were observed flying 1.9 km downstream to Little Hyatt or further downstream to other water bodies to forage (Fig. 1); however, no flights were observed to Howard Prairie. We suggest that Osprey returning to Hyatt nests in spring 1990 used memory of former successful downstream foraging trips to search for fish (instead of unfamiliar Howard Prairie) when resources at Hyatt were absent or scarce. Only a limited number of foraging flights to Howard Prairie were observed in 1990. Although relatively small hatchery trout and steelhead formed the bulk of the diet at Hyatt in May and June 1990, bullhead from downstream waters later in the season were important and lessened (to an unknown degree) the severity of decreased food resources on Osprey productivity.

In 1992 (third breeding season posttreatment), Osprey reproductive rates were below pretreatment rates at both reservoirs (Table 2) as both locations began experiencing drought, which may have been a factor (Fig. 2). Similarly, Sprandel et al. (2002) observed a decline in mean brood size of Osprey during reservoir drawdown in Florida, though Van Daele and Van Daele (1982) observed the opposite at a reservoir in Idaho. Findings from the comparable Osprey population nesting at nearby Howard Prairie were most instructive throughout the study.

Koplin's (1971) concern and caution related to "food loss" effects from rotenone were generally accepted at the time, but no published Osprey/rotenone studies were available. Later, Bowerman (1991) reported significantly lower Bald Eagle productivity rates in Michigan at inland breeding areas treated for rough fish removal within 3.2 km of nests during the treatment year and 2 yr following compared to the same sites in non-treatment years (0.57 vs. 1.30 young/occupied nest). Eagle production was even more reduced when treatment locations were within 1 km of nesting sites (0.39 vs. 1.31). At most lakes in Michigan, fish were manually removed and not killed with rotenone. Other possible human-caused Osprey food shortages include Gardiner's Island, New York (Poole 1989a), where commercial overfishing was perhaps exacerbated by an expanding population of Double-crested Cormorants (*Nannopterum auritum*) and Yellowstone Lake, Wyoming, USA (Baril et al. 2013), where a shortage of Yellowstone cutthroat trout (*Oncorhynchus clarkii*), the Ospreys' primary food source, was reduced dramatically by an illegal introduction of exotic lake trout (*Salvelinus namaycush*), a species not vulnerable to Osprey predation.

The potential adverse indirect food loss on fish-eating birds following fisheries rehabilitation projects using rotenone was addressed earlier by AFS with the response that temporary food reduction likely does not result in significant impacts to most bird or mammal populations because most animals can utilize other nearby water bodies as food sources (Finlayson et al. 2000). Indeed, Hyatt Ospreys returned to their nest sites in 1990, as expected for a Newton (1979) category 3 species, but required fish from nearby waters in addition to the fish provided by the restocking efforts. Nesting Osprey numbers at Hyatt, following rotenone treatment, showed no loss of occupied or active nests, with recruitment rates lower in both 1990 and 1992, but above requirements for population stability. The pair of Bald Eagles at Hyatt seemed less interested in robbing fish from Ospreys and regularly consumed coho salmon carcasses provided as a supplemental food source. Thus, the supplemental food program for eagles likely benefited Ospreys too. Future rotenone projects, with respect to nesting Ospreys, should evaluate: (1) Osprey fall departure and spring arrival times to plan dates for optimum treatment and restocking, (2) potential alternative Osprey foraging locations (fish species present, distances to project, and whether Ospreys nest there) when estimating restocking requirements (especially yearling fish), and (3) relative numbers of nesting Bald Eagles and Ospreys.

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