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OSPREYS (*PANDION HALIAETUS*) IN THE 21ST CENTURY: POPULATIONS, MIGRATION, MANAGEMENT, AND RESEARCH PRIORITIES

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Ospreys (*Pandion haliaetus*) are remarkable raptors. Their choice of conspicuous nest sites and surprising tolerance for nesting in nearly intimate association with humans render them an iconic piece of aquatic ecosystems in both marine and freshwater habitats across the northern hemisphere and much of Australasia (Australia to Indonesia). Wintering in Central and South America and Africa as well, they are among the few truly cosmopolitan birds of prey.

Ecologically, they might be termed generalized specialists. They are, with exceptions so rare that they can safely be ignored, obligate fish eaters. From their talons to the tip of their bill, every bit of an Osprey's morphology is adapted to taking fish from the water and consuming them efficiently. Beyond this specialization, however, they are remarkably catholic in the species of fish that they prey on (Poole et al. 2002). Inland, the predominant fish species caught vary from watershed to watershed. Along the coasts, the fish brought to the nest will change through the breeding season as different prey species migrate in and out of the hunting range of local populations.

Most notably, because they are perched atop a long food chain, they are vulnerable to, and dramatic indicators of fat-soluble contaminants in the environment. In the 1960s and 1970s this led the species to play a pivotal role in the identification of DDT as a major threat to aquatic ecosystems and the banning of its use in the U.S.

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20TH CENTURY STUDIES

Pesticides and Populations. Prior to the 1970s, there were only scattered papers published, mostly on the distribution and natural history of the species, dating as far back as mention of the 300-pair colony on Gardiners Island in Wilson's *American Ornithology* (Wilson 1812). But it was really only in the 1970s, after regional population sizes had fallen so dramatically, that studies of Ospreys began to appear outside of the ornithological journals.

As other regional populations also declined during this period, the Ospreys in southern New England and Long Island, NY were particularly hard hit by a combination of the chlorinated hydrocarbons DDT, which was sprayed indiscriminately on marshes and agricultural fields, and dieldrin, which flowed into Long Island Sound from textile mills along the Connecticut River (Wiemeyer et al. 1975). The number of breeding pairs in this area collapsed from approximately 1000 pairs in the 1940s to just over 100 by the early 1970s (Spitzer 1980). Spitzer's research on this population helped

identify DDT as the cause of the decline (Spitzer et al. 1978, Spitzer 1980), and a precedent-setting lawsuit forced Suffolk County to stop spraying DDT on Long Island salt marshes and set in motion the process that led to the 1972 federal ban on the use of DDT in the U.S.

After the DDT ban, much of the literature published on Ospreys in the 1970s and 1980s dealt with population monitoring and toxicology. Three symposia were organized, one in Williamsburg, Virginia in 1972 (Ogden 1977), one in Montreal in 1981 (Bird et al. 1983), and another in Florida in 1983 (Westall 1984), to review the status of the recovery. The published proceedings from these meetings set the stage, in many ways, for the next generation of research on Ospreys in North America. Key topics included: research techniques, especially those involved in population monitoring; behavioral and migration studies; conservation methods, with a focus on artificial nest sites and hacking of young birds; and levels of contaminants in various populations. Coverage was surprisingly broad, with studies from British Columbia to Florida, and from the Caribbean to Maine and the Great Lakes. Notably lacking were studies of diet and foraging ecology, as well as of Ospreys on their wintering grounds—gaps that we have started to fill only recently.

Migration Studies. Among raptors, Ospreys are easy to band. In their overview of band return data, Poole and Agler (1987) reported that roughly 18 000 had been banded in North America prior to 1985. Since then more than 35 000 have been banded (U.S.G.S. Bird Banding Laboratory 2013). Most of both groups were banded as nestlings. The numbers from Europe are similarly impressive. In Finland alone, over 41 700 have been ''ringed'' (Saurola et al. 2013). That rich database provided a broad-brush overview of the migration of North American and European Ospreys (Henny and Velzen 1972, Kennedy 1973, Osterlof 1977, Poole and Agler 1987, Saurola 1994, Mestre and Bierregaard 2009).

However, it was not until the mid-1990s, when satellite transmitters were miniaturized to 35 g, that we were able to reveal the fine details of Osprey migration. The first satellite transmitters were deployed on Ospreys in 1995 both in Europe and North America. Since then, through 2013, over 450 Ospreys have been satellite tagged (Table 1). The first generation of transmitters had batteries that lasted about a year and were accurate to 100 m at best, with most locations accurate to 1 km or more. This was sufficient to describe the routes and timing of migration in detail unavailable from banding returns (Hake et al. 2001, Martell et al. 2001), but inadequate to report on local habitat use.

Osprey-human Interactions. Few raptor species are so entwined with our own as are Ospreys. In both Europe and North America, DDT and other chemical pollutants depressed reproductive output to the point that populations declined. In Europe, shooting and egg collecting added further pressures to the species (Poole 1989, Dennis 2008).

While Ospreys were being heavily persecuted by hunters and egg collectors in Europe, the species enjoyed a much more sympathetic, if not symbiotic, relationship with humans in North America. For example, in the late 19th century farmers around Mount Hope Bay in Rhode Island provided nesting platforms for Ospreys near their homes. Ospreys got secure nesting locations and farmers presumably lost fewer chickens because Ospreys would drive Red-tailed Hawks (*Buteo jamaicensis*) away from their farmyards (Bent 1937).

In the 1970s and 1980s, as DDT worked its way out of aquatic ecosystems, reproduction improved and populations began to increase. Humans played an important role in the process. The first step was banning the use of DDT. The practice of providing nest platforms was revived in the 1960s at the mouth of the Connecticut River and later in other locations. Ospreys took readily to both nest platforms and other human-made structures in their environment.

Because male Ospreys rarely nest far from where they were born, populations are slow to spread and unlikely to colonize favorable habitat far from existing nesting populations (Poole 1989). Reintroduction programs were initiated across the U.S., Great Britain, and Europe. Searches of publication databases and internet websites indicate that in the U.S. at least 1386 young Ospreys were released at sites spread across 14 states (Table 2). The first introductions began in 1980 (e.g., Rymon 1989) and some are ongoing both in the U.S. and Europe.

INTO THE 21ST CENTURY

In 2008, realizing that it had been 20 yr since anyone had convened a group of Osprey researchers to discuss the ''state of the species'' in North America, Alan Poole, Rob Bierregaard, Brian Washburn, Mark Martell, and Brian Dorr organized a symposium entitled ''Contemporary Issues in Osprey Conservation and Management,'' as part of the 2008 American Ornithologists' Union conference

in Portland, Oregon. The geographic focus of the six papers presented was North American, and a broad range of topics was covered, including the post-DDT population recovery, satellite-telemetry studies of winter ecology and spring migration, and various aspects of the species' interactions with humans.

This special issue of *The Journal of Raptor Research* had its genesis at that meeting. After the symposium, we decided to publish the proceedings. However, we realized that our coverage was limited geographically, so we invited researchers from other continents to contribute papers dealing with the same topics, thus providing a worldwide perspective on Ospreys in the 21st century.

Population Studies. Osprey populations have, with only rare exceptions, been increasing and expanding ever since the 1970s in both North America (Poole et al. 2002) and the western Palearctic (Schmidt-Rothmund et al. 2014).

This issue includes updates on all four Osprey subspecies. Bierregaard et al. (2014) report on the recovery of the population of the North American subspecies (*P. h. carolinensis*) between New York and Boston, which was so heavily decimated and played such a prominent role in the DDT story. That population now exceeds pre-DDT levels but has a very different distribution than prior to the crash. Wiley et al. (2014) review the poorly known and rare Caribbean subspecies (*P. h. ridgwayi*), which may be at some risk. Schmidt-Rothmund et al. (2014) report that the Eurasian Osprey (*P. h. haliaetus*) numbers have increased substantially since the 1980s, despite some areas where the species still suffers some persecution. Finally, Dennis and Clancy (2014) report on the status of the Australasian Osprey (*P. h. cristatus*) in the Australian portion of the subspecies' range.

Migration. Solar-powered batteries, introduced in 1996, enabled us to track individual birds through sequential migration cycles (Alerstam et al. 2006), and GPS functionality, first available in transmitters small enough for Ospreys around 2005, with an accuracy to roughly 15 m permitted landscape-level analyses of habitat use and investigation of such details of migration as wind-drift correction (Klaassen et al. 2011).

In this issue, Martell and his coauthors (2014) present us with the companion piece to the 2001 study of fall migration in North American Ospreys (Martell et al. 2001), describing details of spring migration in the species. Washburn et al. (2014) took advantage of the GPS accuracy to describe habitat use by North American Ospreys overwintering in South America.

Two migration studies in this issue relied on less high-tech methods. Rodríguez-Santana and his team (2014) documented the Osprey migration along the Sierra Maestre mountains in southeastern Cuba, just west of Guantánamo Bay. As Martell et al. (2001) documented, virtually all east coast and many midwestern Ospreys funnel through Florida to Cuba and then Hispaniola on their way to South America. Average fall counts of over 5000 migrating Ospreys were logged over the three-year study by Santana's team of hawk watchers. Finally, Saggese et al. (2014) reports on the apparently growing number of Ospreys that winter as far south as Argentina. These ''over-achieving'' migrants are found throughout the year in northern Argentina and their numbers suggest that the importance of the area for overwintering and young Ospreys has been underestimated.

Osprey-human Interactions. So many species of wildlife are moving into suburban and urban spaces that universities are now offering specializations in urban ecology, and the nascent field has its own journal. Ospreys have been in the vanguard of this invasion and are now, in many areas, inextricably enmeshed with our species.

Ospreys benefit from our intentional or unintentional provisioning of nesting substrates; but, as Washburn (2014) summarizes in this issue, they can cause significant problems when they choose to nest on utility or telecommunications structures. They can also be problematic around airports and fish farms. As their populations continue to increase, there will be an ongoing need for active management of the species.

Given the diversity of chemicals we are introducing into the environment, it is inevitable that some will have deleterious effects on natural ecosystems. One important paper from the original symposium that does not appear in this special issue is the overview that Henny provided of the history of Ospreys and environmental contaminants and the ongoing efforts to search for new threats. Henny et al.'s (2010) encyclopedic review of the topic was published not long after the original symposium. Monitoring of contaminant loads in Ospreys continues to date, with attention being paid to the old and new industrial pollutants as well as the potential for xenobiotic effects of pharmaceuticals in aquatic systems (e.g., Lazarus et al. in press).

Because Ospreys are so conspicuous and dramatic, they are ideal subjects for environmental education. Ironically, as Cushing and Washburn (2014) describe in this volume, the internet—often blamed for taking

Table 1. Ospreys tagged with satellite or cell-tower transmitters in North America and Europe between 1995 and 2013.

LOCATION	PRINCIPAL INVESTIGATORS	START	ONGOING?	ADULTS	JUVENILES	TOTAL	ACCESS TO DATA
North America							
Oregon/ Minnesota/ East Coast	M. Martell	1995	n	74	7	81	Martell et al. 2001, Martell et al. 2014, Movebank.org
Pacific NW	J. Elliott	1996	n	18	0	18	Elliott et al. 2007
Florida/Maine	M. Martell	1999	n	14	0	14	Martell et al. 2004
Eastern N.A.	R. Bierregaard	2000	y	31	38	69	http://www.ospreytrax.com, Movebank.org
Saskatchewan	S. Houston	2001	n	1	0	1	Houston and Martell 2002
South Dakota	W. Mehlquist	2002	n	0	16	16	Mehlquist and West 2011
Labrador	T. Chubbs	2002	n	2	5	7	None
Wisconsin	W. Stout	2002	n	0	3	3	Stout et al. 2009
Ohio	D. Sherman	2005	n	2	0	2	None
Virginia	B. Washburn	2006	n	13	3	16	Martell et al. 2014
Indiana	B. Washburn/ J. Castrale	2006	n	0	3	3	http://gis.larc.nasa.gov/osprey/index.html
Ontario	T. McInnes-Edick	2009	n	2	0	2	Movebank.org
Wyoming	B. Bedrosian	2010	n	3	7	10	http://beringiasouth.org/osprey-migration, Movebank.org
New Hampshire	I. MacLeod/ R. Bierregaard	2011	y	3	7	10	http://www.nhnature.org/programs/project_ospreytrack/index.php, Movebank.org
New York	R. Kennedy	2012	y	2	0	2	http://www.jamaicabayosprey.org/
Montana	R. Domenech	2012	y	3	4	7	http://www.raptorview.org, Movebank.org
Colorado	J. Beason	2013	y	2	0	2	http://www.rmbo.org
Virginia	B. Watts/E. Mojica	2013	n	3	0	3	http://www.ccbbirds.org/ http://wildlifetracking.org/index.shtml?project_id=848, Movebank.org
Michigan	B. Jensen	2013	y	0	3	3	http://www.owsem.org/, Movebank.org
N. A. Total				**173**	**96**	**269**	
Europe							
Germany	B.-U. Meyburg	1995	n	27	1	28	Meyburg and Meyburg 2002
Germany	D. Schmidt/B.-U. Meyburg	1995	n	2	0	2	Schmidt and Meyburg 1998
Sweden	M. Hake, T. Alerstam	1995	n	12	6	18	Hake et al. 2001, Alerstam et al. 2006, Movebank.org
Rutland	T. Mackrill	1999	y	0	15	15	Bolt and Appleton 2001, http://www.zen88810.zen.co.uk/ROspreys%20site/Satellite.htm
Scotland	R. Dennis	1999	n	6	7	13	Galarza and Dennis 2009
Finland	P. Saurola	2001	y	15	3	18	http://www.luomus.fi/en/finnish-satellite-ospreys

Table 1. Continued.

LOCATION	PRINCIPAL INVESTIGATORS	START	ONGOING?	ADULTS	JUVENILES	TOTAL	ACCESS TO DATA
Spain	M. Ferrer/Muriel	2003	n	0	13	13	Muriel et al. 2010, Movebank.org
Estonia	U. Sellis	2006		4	0	4	http://birdmap.5dvision.ee/index.php?lang=en
Scotland	R. Dennis	2007	y	6	12	18	http://www.roydennis.org/animals/raptors/osprey/satellite-tracking/
Norway	R. Kroglund	2007	n	0	8	8	None
Loch Garten	RSBP	2008	y	6	10	16	http://www.rspb.org.uk/wildlife/tracking/lochgartenospreys/
Rutland	T. Mackrill	2011	n	3	0	3	http://www.ospreys.org.uk/
Wales	E. Evans	2011	y	0	4	4	http://dyfiospreyproject.com/meet-the-ospreys/gps-tracking
Loch of the Lowes	Scottish Highlands Trust	2012	y	6	2	8	http://scottishwildlifetrust.org.uk/things-to-do/osprey/
Latvia	U. Sellis/Kalvans	2012		2	0	2	http://www.luomus.fi/en/node/1317
Basque Country	A. Galarza	2013	y	0	5	5	http://www.birdcenter.org/en/about-us/urdaibai-ospreys
Canary Islands	M. Hernández	2013		0	2	2	None
Italy, Corsica, Belearics	A. Sforzi/F. Monti	2013		7	10	17	None
Europe Total				**96**	**98**	**194**	
All Ospreys tagged				**269**	**194**	**463**	

our attention away from the natural world around us—is ideally suited to reconnect us to nature. Nest cam websites with chat room sessions led by experienced researchers are ideal educational vehicles. Interactive sites tracking satellite-tagged birds are likewise excellent opportunities for outreach.

Future Research and Management. Although the Osprey has been one of the most studied raptors, there is a continuing need to advance our understanding of their ecology. Recent advances in technology now provide us the opportunity to explore aspects of the complex behaviors and movement ecology of Ospreys and other raptors previously beyond our reach. This information is not only valuable science, but will provide the foundation for addressing management decisions related to Ospreys today and in the future.

Environmental contaminants. Ospreys are the ideal ''sentinel species'' (Grove et al. 2009). Although no contaminants have recently (or are currently) affecting Ospreys to any significant extent, and populations are robust across the range of the species, it still behooves us to continue monitoring their populations and blood chemistry for the foreseeable future to ensure new challenges to Osprey populations, and by extension aquatic ecosystems in general, are detected and addressed in a timely manner.

Population trends and citizen science. Few raptor species are more suited to be a subject of citizen-science projects than the Osprey. Although monitoring contaminant levels is important, tracking population trends through simple censuses, often heavily reliant on citizen scientists, is as important, because these surveys can point to populations where contaminant studies should be focused. New England has the longest running data sets on population size and reproductive success, and it is important that these programs be maintained.

Table 2. Numbers of young Ospreys released in the U.S.A. from 1980–2013.

STATE	YEARS	YOUNG RELEASED	WEBSITES AND REFERENCES[a]
California	2000–2001	8	http://www.iws.org/species_osprey.html
Colorado	1990–1993	57	http://jimtolstrup.wordpress.com/2012/04/11/ospreys-return-to-nothern-colorado/
Illinois	2013–	5	
Iowa	1997–??	130	http://www.soarraptors.org/osprey.html
Kentucky	1981–1991	97	http://fw.ky.gov/Wildlife/Documents/2011OspreyUpdate.pdf
Minnesota	1984–1995	144	http://www.dnr.state.mn.us/eco/nongame/success.html
Missouri	1995–1998	29	http://mdc.mo.gov/discover-nature/field-guide/osprey
New Jersey	1985–1989	37	Clark and Jenkins 1993
New York	1980–1987	30	http://www.dec.ny.gov/animals/7088.html
North Carolina	1982–??	11	Brown 1983
Ohio	1996–2007?	282	http://wildlife.ohiodnr.gov/species-and-habitats/species-guide-index/birds/osprey
Pennsylvania	1980–1996	265	Rymon 1989
South Dakota	2003–2010	120	http://gfp.sd.gov/wildlife/management/diversity/osprey-recovery.aspx
Tennessee	1980–1988	165	http://www.tnwatchablewildlife.org/details.cfm?displayhabitat=water&sort=aounumber&typename=WATER&uid=09042418462558819&commonname=Osprey
Total		**1386**	

[a] All websites last accessed 1 August 2014.

Continued banding is certainly warranted. Intensive color-banding in growing populations can provide us with insights into the continuing increase in the species' population and range expansion.

A review of the results of the reintroduction projects undertaken across North America and Europe would be welcome. Currently, information about these projects has rarely been published in the peer-reviewed literature, and most of it is buried deep in the grayest of the ''gray'' literature.

Prey. Data on prey species taken should be collected. The legions of nest-cam followers could be enlisted to record prey species delivered and the rate of prey delivery to nests. In 2014, there were at least 30 Osprey nests streaming online, many of them with avid watchers noting and discussing everything happening in the nests. Another attractive possibility would be coupling automated cameras at nests with adult males tagged with GSM transmitters to identify where fish are being caught and provide insights into foraging strategies.

Will prey species change with changing global climate and increased pressure on prey species by human fisheries? The Atlantic menhaden (*Brevoortia tyrannus*) is one of the Osprey's preferred prey species along the northeastern coast of North America (Poole 1989), and one whose numbers have been dramatically reduced by overfishing (see Bierregaard et al. 2014). What will happen along the Atlantic coast of the northeastern U.S. now that actual management of the fishery harvesting has been implemented? We will only be able to answer these questions if we have an adequate data set from a number of different regions over a substantial time period.

Migration and movement data. A meta-analysis of survival rates and reproductive success of satellite-tagged Ospreys, both of which seem abnormally low, is a high priority. Pending the results of such a review, many data already archived from tagged birds remain to be analyzed. This is especially true of birds outfitted with the new GSM transmitters, which download data via cell towers rather than satellites and can now register and transmit over 100 000 data points per year from one bird. In fact, one high priority is to develop statistically valid analytical methods to deal with such a daunting stream of data.

There is much science to be done on a remarkably charismatic and easy-to-study species. Let's get to work!

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