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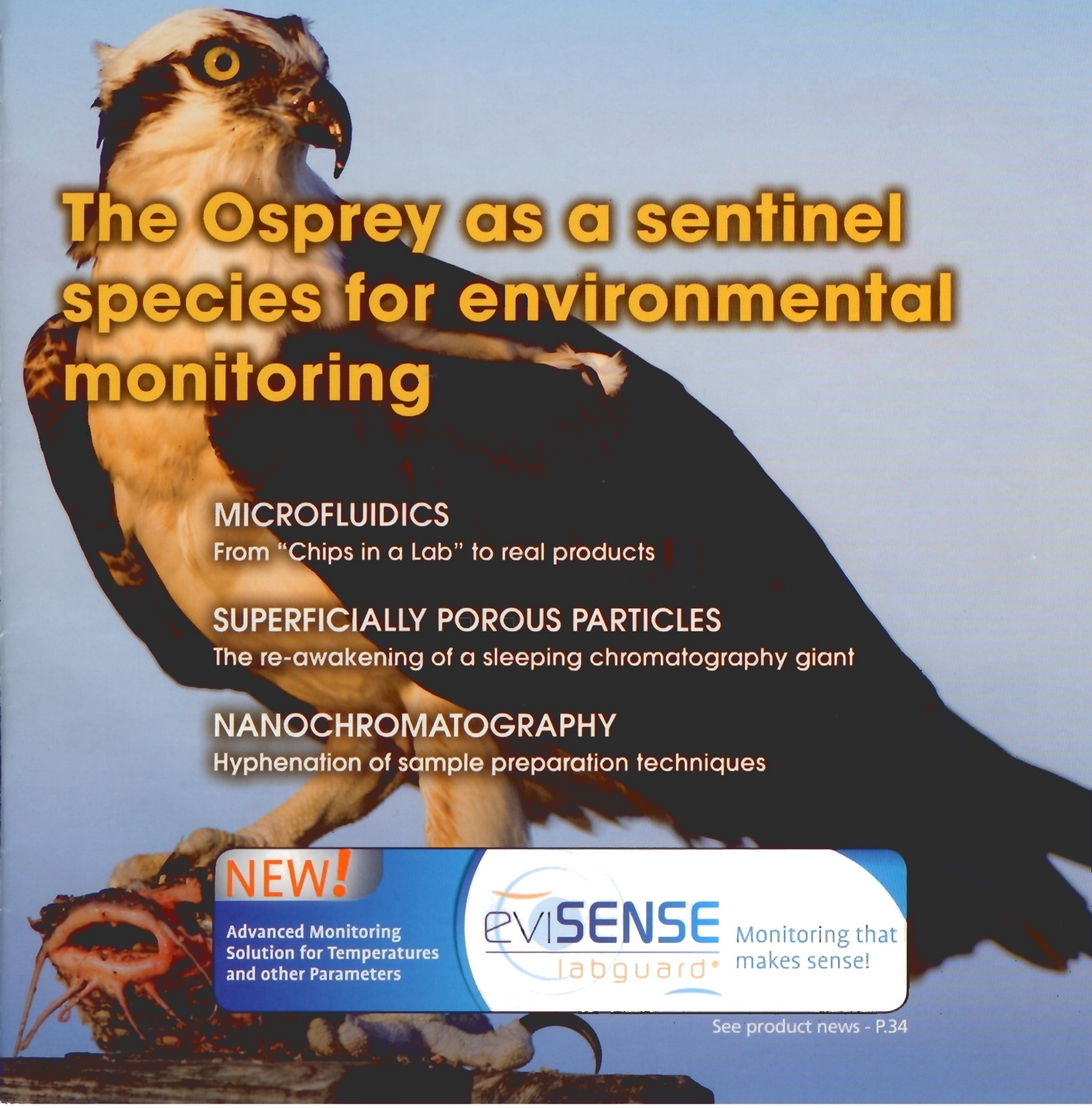

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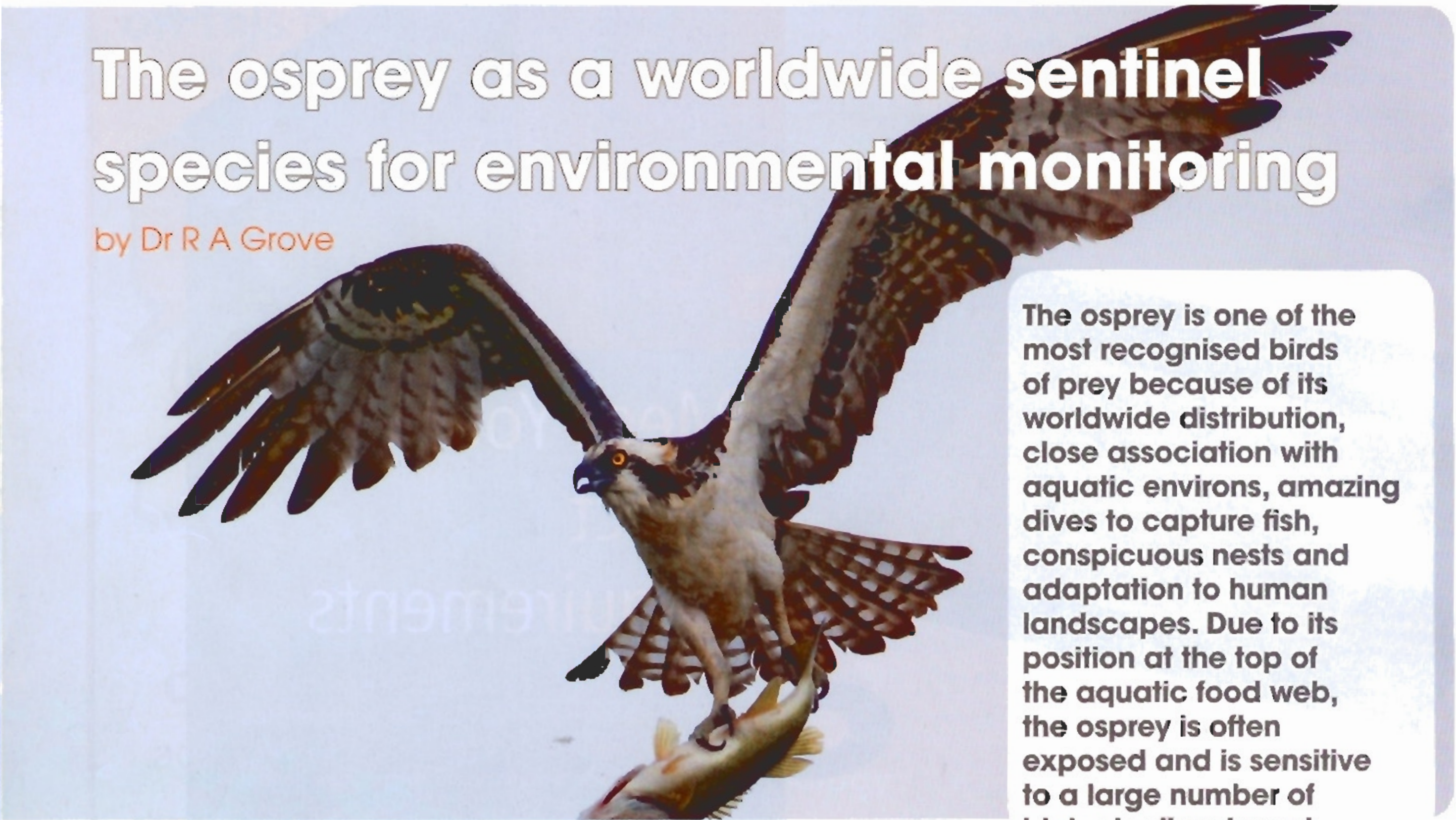
Environmental analysis

The osprey as a worldwide sentinel species for environmental monitoring

by Dr R A Grove



The osprey is one of the most recognised birds of prey because of its worldwide distribution, close association with aquatic environs, amazing dives to capture fish, conspicuous nests and adaptation to human landscapes. Due to its position at the top of the aquatic food web, the osprey is often exposed and is sensitive to a large number of *biologically relevant* contaminants that are known to bioaccumulate or biomagnify. Several biological traits of the osprey have been instrumental in understanding the species' spatial distribution and abundance over time, and how exposures to these contaminants affect their overall health and reproductive success. Studies throughout the world have shown the osprey to be a useful sentinel species for monitoring selected environmental contaminants, including several emerging contaminants of concern.

Thousands of man-made chemicals have found their way into the environment since the early 1900s. Many of these chemicals are of concern because of their negative impacts on biological systems and persistence in the environment. These environmental contaminants are lipophilic, resistant to environmental or metabolic breakdown; they bioaccumulate or biomagnify up the food web. The adverse effects of environmental contaminants on living organisms depend on the concentration, bio-availability, exposure duration and toxicity of such contaminants. The sensitivity of the species to these chemicals is also an important factor.

Sentinel Species

The concept of using animals as sentinels is not new. Humans and animals that inhabit the same local environs also share common biochemical, molecular and cellular responses when exposed to toxic agents. Because of these commonalities, animals have been used for centuries as early warning to exposure of environmental hazards. An example of which is the canary used in coal mines used to detect the lethal build-up of carbon monoxide, since the species is more sensitive to the odourless gas than humans. By virtue of their position in the food web and selected biological traits (e.g., ability to live in human-altered environments), certain animal species are among the first to be exposed and respond to newly introduced environmental stressors. Due to their position in the food web and their sensitivity to contaminants, sentinel species are important because they can be used empirically to assess contaminant bio-availability, tissue concentrations present and effects related to contaminant exposure [1].

Animal studies under controlled laboratory conditions are important in determining causation, dose-response relationships and molecular mechanisms of action from single chemical exposures. However, single chemical studies have limited use in understanding the complex biological responses of fish and wildlife exposed to real-world concentrations of contaminant mixtures. Therefore, animal species studied outside the laboratory provide important information on contaminant exposure routes and effects under natural settings.

The osprey as sentinel species

Over the years, several animal species have been studied by scientists in localised areas to quantify both contaminant exposure and effects, especially with regard to reproduction. The large fish-eating osprey has a nearly world-wide breeding distribution, and utilises both salt and fresh water habitats. As a result of its distribution and position atop the aquatic food web, its ability to accumulate lipophilic contaminants and sensitivity to many contaminants, scientists have often used the osprey for environmental studies. Our group recently published a paper evaluating the osprey as a worldwide sentinel species for assessing and monitoring environmental contaminants in aquatic settings [2]. Several osprey life history traits make it a species of choice for contaminant monitoring and research, justifying its use as a sentinel species [Table 1].

The osprey is known to be sensitive to many of the contaminants found in aquatic ecosystems, including DDTs, other organochlorine insecticides, PCBs, dioxins, furans and mercury.

Testing for environmental contaminants

The osprey is not amenable to conducting laboratory studies, primarily due to difficulties related in captive rearing. However, osprey eggs have been collected from nests in the field and successfully incubated under laboratory conditions to determine developmental effects and biochemical changes resulting from maternal contaminant exposure. Yolk sacs collected from freshly hatched osprey chicks were analysed for contaminants and the results compared with chick hepatic P4501A protein levels and ethoxyresorufin-o-deethylase activity, vitamin A and retinol concentrations in blood, liver and kidneys, hepatic porphyrin levels and histological observations. This study and others have shown that developing bird embryos are consistently more sensitive than at other life stages to contaminants like PCBs, dioxins and mercury. Thus, artificial incubation of field-collected osprey eggs allows for the detection of chick deformities and perturbations of a variety of biochemical and physiological endpoints associated with contaminant exposure. In the late 1960s, both osprey eggs and chicks were used to evaluate the effects of DDT on osprey reproduction by exchanging the eggs and young of nests from relatively clean areas in Maryland with nests from heavily contaminated areas in New Jersey. The studies showed DDT and its metabolites were indeed the causative agents affecting reproduction by separating the intrinsic effects of contamination in the eggs and young from the extrinsic effects of adult behaviour and food availability (Spitzer 1978). Tolerance of short-term nest disturbance and osprey nesting on accessible structures permitted this approach to work successfully.

Over the last several decades, osprey studies throughout the world have focused on the

- Almost exclusive fish diet.
- Foraging at short distances from the nest.
- Long-lived species (25 years) with strong nest site fidelity, using the same or adjacent nest sites each year,
- Readily observable nests at exposed locations (often on artificial structures), easily detected by surveys,
- Adaption to human landscapes including industrial/municipal sites where contamination may be highest.
- Readily habituates to human activity, tolerates short-term nest disturbance for egg/blood collection.
- Nests spatially distributed at regular intervals along waterways, permitting random egg and tissue collections along river segments.

Table 1. Characteristics of the osprey that make it ideal as a sentinel species.

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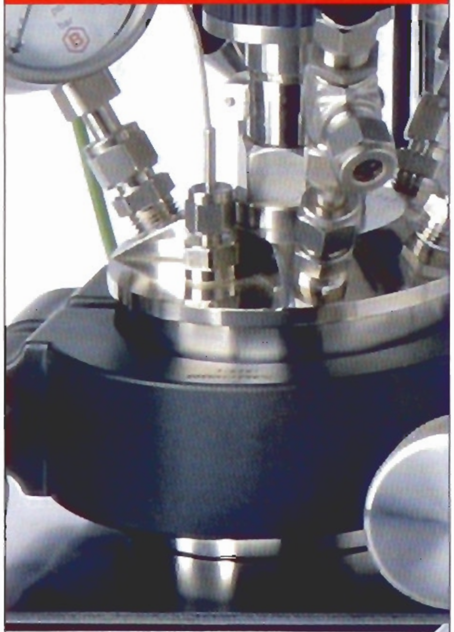

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Environmental analysis

(1) DDTs and other OC pesticides, PCDDs, PCDFs, PCBs, mercury and other metals for examining possible effects on reproduction.
(2) Lead exposure and accumulation from mining activities for examining possible effects on blood parameters, survival and reproduction.
(3) Various marker contaminants, to estimate empirical biomagnification factors from fish to osprey eggs.
(4) Emerging contaminants, including PBDE, PFOS, herbicides and fungicides, to determine exposure and possible effects.

Table 2. Environmental contaminants measured using ospreys as sentinel species

following issues: (1) species composition of fish in the osprey diet, (2) population numbers and changes over time, (3) spatial contaminant residue patterns relative to known point sources, or along major rivers and estuaries and (4) effects of various contaminants on reproductive success, including the percent of populations adversely affected. In addition to long-term contaminant monitoring of regional osprey populations, local populations have also been studied to evaluate selected contaminants [Table 2]. As with other bird populations, the status of North American osprey populations in the mid-1960s received little attention until a population crash of a Connecticut River nesting colony in North-Eastern United States, was reported , implicating pesticides as the cause. A severe 30% annual decrease in the adult nesting population was noted along with exceptionally poor productivity of 0.23 young fledged per nest. Shortly after, similar findings of poor osprey productivity and declining population numbers were reported elsewhere. At that time in the mid-60s, the number of young produced per nest needed to maintain a stable population was not known. A population model was developed to estimate survival and production rates needed to maintain stable osprey populations using primarily eastern US osprey banding data. After model refinement, it was estimated that 0.8 young per nesting attempt was needed to maintain a stable osprey population. Though nestling survival appeared normal, the number of young fledged per nest in several studies was well below the 0.8 young threshold needed for maintaining a stable osprey population. Inspections of osprey nests revealed large numbers of eggs were failing to hatch, with some eggs disappearing during incubation for reasons unknown. Scientists discovered hatching failure was due to thin shelled eggs cracking or breaking rather than from adult infertility or ability to breed. It was found that DDE (a neurotoxic pesticide) inhibited prostaglandin synthesis of the eggshell gland mucosa, interfering with calcium metabolism. The resultant thin shelled osprey eggs were highly susceptible to breakage during incubation. Further research found 15 and 20% eggshell thinning of osprey eggs was associated with 4.2 and 8.7 ppm (w/w) DDE. Studies of other raptor species concluded that no raptor population exhibiting ≥18% eggshell thinning was able to maintain a stable self-perpetuating population. Therefore, mean DDE concentrations in osprey eggs between 4.2 and 8.7 ppm were hypothesised to result in declining populations. Data from our osprey nesting studies in the Pacific Northwest from 1993 to 1998 verified the reproductive relationships, with eggs at nests containing <4.2, 4.2-8 and ≥8 ppm DDE from the Columbia River System producing 1.61, 1.25 and 1 young/active nest, respectively. Eggshell thinning followed a classic semi-logarithmic DDE response to the three DDE categories of 3.4%, 12.7% and 17%. By 2004, DDE concentrations in osprey eggs from the Lower Columbia River were all below the 4.2 ppm threshold, no longer influencing osprey reproduction. A continued decline of this pesticide has been shown in other studies throughout the United States, Canada, Europe and elsewhere since its ban in the 1970-80s.

In one of the first studies of the effect of environmental contaminants on the osprey, it was found that certain concentrations of DDE, a metabolite of DDT, resulted in a thinning of the egg-shell, increasing the likelihood of egg breakage. This meant that the number of successfully fledged young birds fell below the threshold needed to maintain a stable adult bird population. The extent of egg-shell thinning correlates with the DDE concentration present. Image courtesy of USGS.

Other organochlorine pesticides (e.g., dieldrin, heptachlor, endrin) have also declined significantly since their ban in the 1970s and 80s, with current concentrations well below any effect levels. Results from recently completed long term surveys have shown dramatic increases in nesting populations of ospreys for both North America and Europe. These increases now appear limited by nest site availability, food resources and perhaps contaminant exposure in heavily polluted areas.

Polychlorinated biphenyls (PCBs), dioxins and furans are also important environmental contaminants because of their toxicity to fish and wildlife. These industrial contaminants elicit a numbers of responses, including but not limited to, mortality, thymic atrophy, immunotoxicity, reproductive impairment, porphyria and other liver damage. Since the US ban of PCB manufacture in 1979, several osprey studies have shown these compounds gradually decreasing in the environment, with declines as much as 50% in eggs and tissues occurring every five to 10 years. Dioxins and furans, major by-products of bleach-kraft pulp mills, were looked for in osprey eggs in the early 1990s after these contaminants were found in the tissues other fish eating bird species. Significant decreases in osprey egg concentrations of the lower chlorinated dioxins and furans (the more toxic congeners) have been documented in several studies since curtailment of the chlorine bleaching process in the early 1990s, with recent studies from the US and Canada reporting concentrations in the low parts per trillion.

Future perspectives for the osprey as a sentinel species

To effectively measure contaminant distribution and effects in fish and wildlife, it is critical to select those species that will optimise the usefulness of information collected. Suitable sentinel species need to respond to contaminant insults manifested by a broad spectrum of pathologic responses, including reproductive and behavioural dysfunctions, immunologic and biochemical perturbations, and anatomical changes (birth defects). No single species can be used to effectively evaluate all forms of contaminants, necessitating understanding the physiology and biochemistry of those species used and the toxic mechanisms of contaminants in question. Much is known concerning the osprey's life history and biology, which has led to its successful use as a sentinel species in evaluating contaminant exposure and effects in aquatic ecosystems. Ospreys nesting at regular intervals allows for the evaluation of environmental contaminants at random along large river segments or strategically at sites above and below known or suspected point sources. Understanding their regional diets based on biomass allows for the determination of contaminant contribution of fish species consumed using bio-magnification factors. This approach is currently being used in risk assessments associated with Superfund sites in the US. Recently, the osprey is being used to evaluate the potential exposure and effects of several emerging contaminants of concern, including polybrominated diphenyl ethers. Thus far, however, few studies have compared contaminant levels in osprey tissues with currently implemented biochemical biomarkers. Future research is needed to understand uptake kinetics, effect levels and biological responses to these emerging contaminants of concern, requiring development of new technologies. Taking these considerations into account, we believe the osprey has many characteristics that make it an excellent candidate for evaluating the more recent environmental contaminants of concern.

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2. Grove RA *et al.* Osprey: worldwide sentinel species for assessing and monitoring environmental contamination in rivers, lakes, reservoirs, and estuaries. J Toxicol Environ Health B Crit Rev. 2009;12: 25-44

Further Reading

A complete bibliography is available from the author.

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