

## Seeds consumed by waterfowl in winter: a review of methods and a new web-based photographic atlas for seed identification

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**Abstract** Diet quantification has long been and still is one of the first steps undertaken when studying the basic ecology of a species. We conducted a literature review of the techniques used to study and analyse diet among waterfowl. Even though the identification of food items is the most challenging task performed when studying granivorous waterfowl diet, there is a general lack of reference collections to support the taxonomic determination of food resources. We present here a collection of indexed digital pictures of seeds from the reference collections of several French programs of research into waterfowl diet. Photographs are ranked by seed size or by taxonomic key to ease seed identification. This collection is freely accessible at the website <http://www.cebc.cnrs.fr/atlasofseeds.html>, and it can help wildlife researchers studying the diets of granivorous species to determine food items. A complete bibliography is also provided, including recent papers in archeobotany and useful websites.

**Keywords** Anatidae · Atlas · Diet · Marshland seed determination · Reference collection · Website

### Introduction

Collecting food items and studying field diet are both tedious and time-consuming tasks. Numerous methods have been used over the years to evaluate the diets of bird species, including pellet dissection (Elton 1927), flushing and forced regurgitation (Ridoux 1994), and direct observations (see Rosenberg and Cooper 1990 for a review). Recent techniques have also provided indirect methods such as stable isotopes (reviewed in Kelly 2000), or molecular approaches, which are used to identify prey in scats in particular (Höss et al. 1992; Sutherland 2000). Identification of food items may often be difficult because of fragmentation induced by ingestion and/or digestion; therefore, a reference collection of intact food items is a valuable aid. Such reference collections permit the original sizes or weights of ingested foods to be determined from identified fragments (Arzel et al. 2007). Seeds are an exception among food types, since they are often encountered almost intact in digestive tracts and in soil, and are thus suitable for precise quantification of both resource abundance and consumption. The identification and collection of seeds is an essential task in several research fields: (1) the archaeobotanical identification of plants used by humans and the weed flora of ancient crops (see bibliographical review in Nesbitt and Greig 1990; see also Nesbitt et al. 2003); (2) the conservation of rare plant species (e.g., Farnsworth et al. 2006); (3) identifying the compositions of soil seed banks in restoration ecology (although this is more commonly carried out by germinating the seeds and identifying the seedlings: Ter Heerdt et al. 1996; Thomson et al. 1997) or (4) diet (e.g., Gaerskaya 1966; Thomas 1982; Holland et al. 2006).

In this paper we investigated the techniques used to describe the diet of waterfowl in recent ecological studies.

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We searched on two different bibliographical reference databases—the ISI Web of Science and “Duckdata” (UGWS)—using the keywords “diet” and “waterfowl.” We used 44 relevant papers out of the 172 papers initially selected to address the following questions:

1. Which source of information was used to evaluate the diet (droppings, dead animals)?
2. How was the determination of food items carried out?
3. Which food item was determined (animals, plants or seeds)?

We found that only one study (Clark et al. 1986) examined the diet through direct observations, while dropping and digestive tract analyses represented 20.5 and 77% of the studies, respectively. The choice of digestive tract or dropping methodology depended mainly on the food types eaten (seeds, plants or invertebrates). Fecal samples were largely used to describe herbivorous diet (i.e., geese or wigeon) (Durant 2003; Markkola et al. 2003). In our review, the latter methodology was used in half of the studies of herbivorous diet; such an approach requires a reference collection of epidermal tissues. Work on dead animals was carried out when the diet was mainly composed of seeds (95% of such studies); 73.5% of these papers did not mention how the taxonomic determination was carried out. Our review revealed that reference collections were therefore poorly used (they were employed in just

10% of the studies, see Table 1 for details) to determine seed species.

Archaeobotanists have traditionally used seed reference collections (see de Vartavan 1990 for a review of the methodological aspects of collecting and storing seeds). Nesbitt et al. (2003) called for the development of digitally available databases.

We also present here a collection of indexed pictures of seeds from six main French marshes and wet meadows, taken from the reference collections of several collaborative research projects. These marshes and meadows are: (1) Baie du Mont Saint Michel in Normandy, northern France; (2) the Dombes area, located north of the city of Lyon; (3) Gravières du Perthois in the north-east of France; (4) the Brenne area located inland in western France; (5) Baie de Seine, close to the city of Le Havre, and; (6) Marais de Rochefort, on the French Atlantic coast. In the field, seeds were taken on entire seed-bearing plants. Plant determination followed Lambinon et al. (1993) and was double-checked using specialized seed identification books (Martin 1951, 1954; Martin and Barkley 1961; Berggren 1969, 1981; Anderberg 1994). The study sites can be considered to be representative of north-west European marshes and wet meadows (except for some Mediterranean species), based on the broad uniformity of aquatic and tidal environments and the high proportion of widely distributed aquatic and tidal plants (see Santamaria 2002 for a review).

**Table 1** Literature overview of 44 studies dealing with waterfowl diet (listed according to the identification process and material type)

Material	Main food items	Identification				Reference(s)*	Total
		Reference collection	Literature	Unspecified	No identification		
Direct observation	Cereals			2%		1	2%
Droppings	Invertebrates	5%	2%			2–4	7%
	Seeds	2%				5	2%
	Vegetation	7%		5%		6–10	11%
Shot birds	Invertebrates		2%	11%	2%	11–17	16%
	Vegetation	4%		2%	2%	18–21	9%
	?				9%	22–25	9%
	Seeds		2%	7%	2%	26–30	11%
	Seeds and invertebrates		9%	14%	2%	31–41	25%
	Seeds and vegetation	2%		2%	2%	42–44	7%
Total		20%	16%	43%	21%		

\* Reference key: (1) Clark et al. (1986); (2) Collier (1991); (3) Rodway and Cooke (2002); (4) Rodway (1998); (5) Green and Sanchez (2003); (6) Corti and Schlatter (2002); (7) Figuerola et al. (2002); (8) Fox et al. (1998); (9) Giroux and Bergeron (1996); (10) Prop and Deerenberg (1991); (11) Bendell and McNicol (1995); (12) Bustnes et al. (2000); (13) Figuerola et al. (2004); (14) Nummi and Vaananen (2001); (15) Sánchez et al. (2000); (16) Sekiya et al. (2000); (17) Winfield and Winfield (1994); (18) Markkola et al. (2003); (19) McKnight and Hepp (1998a); (20) Alisauskas and Hobson (1993); (21) Summers and Grieve (1982); (22) Mateo et al. (2000); (23) Mazak et al. (1997); (24) Krapu et al. (1995); (25) Ankney and Afton (1988); (26) Petrie (2005); (27) Dabbert and Martin (2000); (28) Nummi (1993); (29) Halse (1984); (30) McLandress and Raveling (1981); (31) Ballard et al. (2004); (32) McKnight and Hepp (1998b); (33) Moore et al. (1998); (34) Thompson and Drobney (1997); (35) Petrie (1996); (36) Eberhardt and Riggs (1995); (37) Afton et al. (1991); (38) Ankney and Alisauskas (1991); (39) Sheeley and Smith (1989); (40) Woodin and Swanson (1989); (41) Noyes and Jarvis (1985); (42) Tietje and Teer (1996); (43) Alisauskas and Ankney (1992); (44) Alisauskas et al. (1988)

The photos were taken with a camera (Hyper HAD, Sony, Tokyo, Japan) fitted over a binocular microscope (Stemi 2000 C, Zeiss, Stuttgart, Germany) with Cyberview 2.5 software (Cervus International, Courtaboeuf, France). Additional information such as geographic location, magnification, size, and taxonomy are available for each seed photograph. Seeds are ranked by size (three size classes, <1, 1–3, and >3 mm, were defined) or by family to make it easier to search through the collection. The data are collected in a MySQL database, and a total of 208 species are available (more than 900 images), including 123 genera and 52 families. Each species is described by a mean of 3.9 images taken at different magnifications. Seeds rank from  $0.3 \times 0.1$  to  $10.5 \times 7$  mm in size (mean =  $2.4 \times 1.5$  mm). The photographs are available at the website <http://www.cebc.cnrs.fr/atlasofseeds.html>. Seeds of 151 species come from plants only, while 31 (15%) come from plants and guts, 13 (6%) from plants and soil, 6 from guts only, and 7 from soil only.

Despite being laborious and time-consuming, stomach content analysis remains the most accurate way of studying waterfowl diet, since other techniques (cited above) only provide a rough/qualitative overview of the diet (Hyslop 1980). Carcass analysis provides the most complete information on diet, and it also allows the taxonomic determination of food items to a high taxonomic resolution. Our extensive literature review of the techniques used to study waterfowl diet revealed that reference collections were used in only 20% of the studies, which could call into question their validity. Following the recommendations of Nesbitt et al. (2003) concerning future developments in seed reference collections, we believe that our online atlas will help to fill this gap. Our web-based atlas provides a useful aid to identifying an unknown seed species. Since the seeds mainly come from plants in North European marshes and wet meadows, this online atlas will prove most useful for studies aimed at determining the diets of

granivorous species (mainly waterfowl) and soil seed banks from those habitats. While the reference atlas does not present an exhaustive list of seeds from the different study areas, it may be used in conjunction with other websites (Table 2). Since many aquatic/tidal plants are widely distributed in temperate latitudes (Santamaria 2002), other information resources on digitized seed collections can be found on Internet websites, including ones from North America (see Table 2 for some useful websites). Our atlas also allows a novice engaged in stomach content analysis (of ducks for example, see also Campredon et al. 1982) to easily identify the seed family, though a more experienced researcher may use it for verification or for further identification to the species level. Seeds found in the diet or in seed banks have very different appearances, since they are typically darker and lack exterior parts such as style bases or achene walls. It is worth noting that 27% of the seeds in the atlas come from either gut or soil samples and from wild plants, thus allowing the taxonomic determination of altered seeds. We hope that ongoing studies of French and Western European wetlands will continue to increase the taxonomic and biogeographic coverage of the taxa included in this atlas.

### Zusammenfassung

Samen als Winternahrung von Wasservögeln:  
Ein Überblick über die Ernährungs-Methodologie  
und einen neuen web-basierten Foto-Atlas zur  
Samenbestimmung

Die Quantifizierung von Nahrungsbestandteilen war schon lange einer der ersten Schritte bei der Erforschung der ökologischen Grundbedürfnisse einer Art und ist dies bis heute geblieben. Wir haben aus der Literatur Methoden zusammengetragen, die zur Nahrungs-Untersuchung und -

**Table 2** Useful websites for seed identification

Source	Web URL	Availability
The Digital Seed Atlas of The Netherlands	<a href="http://www.seedatlas.nl/">http://www.seedatlas.nl/</a>	Free access
SeedImages.com from the University of Colorado	<a href="http://www.seedimages.com/">http://www.seedimages.com/</a>	Limited access
Interactive Encyclopedia of North American Weeds	<a href="http://www.thundersnow.com/weedid.htm">http://www.thundersnow.com/weedid.htm</a>	CD-Rom, limited access
Seed ID from the Department of Horticulture and Crop Science at Ohio State University	<a href="http://www.ag.ohio-state.edu/~seedbio/seed_id/index.html">http://www.ag.ohio-state.edu/~seedbio/seed_id/index.html</a>	Free access to 233 species
Bioimages.org	<a href="http://www.bioimages.org.uk">http://www.bioimages.org.uk</a>	Free access
HYpermedia for Plant Protection—Weeds	<a href="http://www.dijon.inra.fr/hyppa/hyppa-a/hyppa_a.htm">http://www.dijon.inra.fr/hyppa/hyppa-a/hyppa_a.htm</a>	Free access
The Seed Site	<a href="http://theseedsite.co.uk/">http://theseedsite.co.uk/</a>	Free access
Seed for Free	<a href="http://seed.for.free.fr/">http://seed.for.free.fr/</a>	Free access (in French)
Atlas of Seeds	<a href="http://www.cebc.cnrs.fr/atlasofseeds.html">http://www.cebc.cnrs.fr/atlasofseeds.html</a>	Free access

Analyse bei Wasservögeln verwendet wurden. Obwohl die Identifikation von Nahrungsbestandteilen der schwierigste Teil bei der Ernährungsuntersuchungen Körner fressender Wasservogel darstellt, fehlen im allgemeinen Referenzzsammlungen, die die richtige taxonomische Einordnung der Nahrungsquellen erleichtern. Wir stellen hier eine Sammlung indizierter Digitalaufnahmen von Samen vor, die von referenzierten Sammlungen verschiedener französischer Forschungsprogramme an Wasservogelnahrung kommen. Um die Bestimmung der Samen zu erleichtern sind die Aufnahmen nach Samengröße oder taxonomischen Schlüsselns sortiert. Die Arbeit ist auf der Web-Seite <http://www.cebc.cnrs.fr/atlasofseeds.html> frei zugänglich und soll Freilandforschern, die die Nahrung von granivoren Arten untersuchen, helfen, Nahrungsbestandteile zu bestimmen. Außerdem wird eine komplette Bibliographie bereitgestellt, die aktuelle Veröffentlichungen in Archäobotanik und hilfreiche Web-Seiten beinhaltet.

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