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Habitat use of the Aquatic Warbler (*Acrocephalus paludicola*) in Lithuania 2011

Diploma thesis

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Abbreviations

AIC	Akaike Information Criterion
ωAIC	Akaike weight
ΔAIC	delta AIC, the difference in AIC-values from a selected model *i* to the model with the lowest AIC-value
BEF	Baltic Environmental Forum
c.	circa
cf.	confer
C/N	carbon-nitrogen-ratio
E	East
e.g.	for example
et al.	and others
GIS	Geographic Information System
GPS	Global Positioning System
ha	hectare
i.e.	that is
km	kilometre
km^2	square kilometre
LOD	Lithuanian Ornithological Society
m	metre
m^2	square metre
MAD	median absolute deviation
Mi	Minija (study area)
n	number
N	nitrogen
N	North
Nd	Nemunas delta Regional Park
OM	organic matter
OTOP	Polish Society for the Protection of Birds
pers. comm.	personal comment
Ru	Rusne (study area)
SD	standard deviation
Sg	Sausgalviai (study area)
Sk	Sakuciai (study area)
Sv	Svencele (study area)
Sy	Sysa (study area)
Ty	Tyrai (study area)

Abstract

The Aquatic Warbler (*Acrocephalus paludicola*) used to be a common bird breeding in fen mires all over Europe in the beginning of the 20th century. Due to large scale habitat loss it has disappeared from most of its former range. Nowadays the Aquatic Warbler is the only globally threatened passerine bird of mainland Europe.

Subject of this study is a small, currently declining Aquatic Warbler population breeding in the floodplain meadows of the Nemunas delta and at the shore of the Curonian lagoon in southwest Lithuania. In contrast to all other known Aquatic Warbler breeding habitats the meadows of the Nemunas delta are agriculturally used for hay harvest.

Research aimed at:

- The identification of vegetation structure parameters influencing Aquatic Warbler habitat selection in the Nemunas delta.

- The investigation of general breeding biology and an analysis of breeding success of the Lithuanian Aquatic Warbler population.

- The assessment of the impact of meadow harvest on Aquatic Warblers breeding in the Nemunas delta.

- The development of management recommendations. These recommendations focus on maintaining habitat quality suitable for the Aquatic Warbler and on the protection of Aquatic Warbler nests over the whole breeding season.

In total 128 vegetation plots were sampled in the Nemunas delta and adjacent regions in 2006 and 2011. Data sampling took place in the beginning (2006 & 2011) as well as during the breeding season (2011). Soil samples were analysed for C/N-ratio and OM content (all data from 2006 are from Tanneberger et al. 2010). Aquatic Warbler nests were searched for in two breeding areas of the Nemunas delta (Sysa and Sausgalviai) and in Tyrai mire at the shore of the Curonian lagoon over the whole breeding period in 2011. In total 15 nests were found. Singing males surveys were carried out in the beginning of June and July. Management recommendations for the protection of Aquatic Warbler nests were developed based on the distances between nests and singing males. A monitoring of the meadow harvest was carried out over the whole breeding season. The proportion of the area where Aquatic Warbler nests had to be expected lost due to mowing was calculated.

Vegetation structure variables influencing Aquatic Warbler habitat selection in the Nemunas delta could not be statistically identified with Generalized Linear Mixed Models (GLMM). This might be due to a lack of sites without Aquatic Warbler records in the dataset. In addition the time frame of the study as well as the spatial scale might have been insufficient. Some parameters not tested might have been the main factors regulating the distribution of Aquatic Warblers, e.g. meadow harvest or prey availability. Nevertheless it can be concluded that Aquatic Warbler breeding areas in the Nemunas delta belong to the floodplain habitats, where a low litter layer and a low water table are crucial in nest site selection. Aquatic Warbler breeding areas in the Nemunas delta mostly resemble to the Pomeranian sedge sites. The Nemunas Delta sites belong to the most eutrophic Aquatic Warbler breeding sites. Peat mineralisation in the Nemunas delta will maintain a high soil nutrient availability and therefore a high productivity of the vegetation. In order to prevent vegetation succession and to maintain habitat quality suitable for the Aquatic Warbler an early onset of hay harvest and two cuts per year should be facilitated in areas where Aquatic Warblers are absent. Water tables should not be lowered far below the soil surface.

Findings on general breeding biology of the Lithuanian Aquatic Warbler population are in accordance with findings from previous studies. Breeding success of Aquatic Warblers (according to the Mayfield method) in the Nemunas delta is markedly lower than in habitats where land use is only carried out within conservation management. Nest losses due to mowing were observed in the Nemunas delta and the area where Aquatic Warbler nests were to be expected was greatly reduced with the progress of meadow harvest. It is therefore concluded that meadow harvest imposes a serious threat on Aquatic Warblers breeding in the Nemunas delta. With 1.59 fledglings per nest breeding success of the Lithuanian Aquatic Warbler population is not sufficient to maintain population size if females can only rear one brood per breeding season. Therefore the survival of every single nest initiated during the whole breeding season should be safeguarded. Aquatic Warbler nests in the Nemunas delta were located within a distance of 116 m to the nearest male singing during the nesting period. It is recommended to carry out a singing males survey in the beginning of June. The area within a radius of 120 m around each recorded singing male has to be spared from mowing until at least August 15th. This will enable the protection of the early and the late Aquatic Warbler brood.

Zusammenfassung

Der Seggenrohrsänger (*Acrocephalus paludicola*) war in weiten Teilen Europas noch am Anfang des 20. Jahrhunderts ein häufiger Brutvogel der Niedermoore (Schulze-Hagen 1991). Wegen großräumigem Lebensraumverlust ist die Art in weiten Teilen ihres ehemaligen Verbreitungsgebietes verschwunden. Heute gilt der Seggenrohrsänger als die einzig global bedrohte Singvogelart Mitteleuropas (AWCT 1999).

Gegenstand der vorliegenden Arbeit ist eine kleine, gegenwärtig abnehmende Population des Seggenrohrsängers, die in feuchten Grünlandwiesen des Nemunas Deltas und an dem östlichen Ufer des Kuhrischen Haffs in Südwest Litauen brütet. Die Brutgebiete des Segenrohrsängers im Nemunas Delta unterscheiden sich von allen anderen bekannten Brutgebieten dadurch, dass sie landwirtschaftlich genutzt werden (Heugewinnung).

Schwerpunkte der Untersuchung waren:

- Die Identifizierung von für die Ansiedlung von Seggenrohrsängern relevanten Vegetationsstrukturparametern.
- Die Untersuchung von allgemeiner Brutbiologie und die Analyse des Bruterfolgs der Litauischen Seggenrohrsängerpopulation.
- Die Abschätzung des Einflusses der Heumahd auf die im Nemunas delta brütenden Seggenrohrsänger.
- Die Entwicklung von Managementempfehlungen, die auf den Erhalt einer für den Seggenrohrsänger geeigneten Habitatqualität abzielen und den Schutz von Seggenrohrsängernestern über den gesamten Brutzeitraum ermöglichen.

Insgesamt 128 Vegetationsaufnahmen wurden in den Jahren 2006 und 2011 in verschiedenen Gebieten des Nemunas Deltas und in umliegenden Regionen angefertigt. Die Datenaufnahme fand zu Beginn der Brutsaison (2006 & 2011) sowie währen der Brutperiode (nur 2011) statt. Bodenproben wurden auf C/N-Werte und den Gehalt an organischer Substanz untersucht (Daten von 2006 stammen von Tanneberger et al. 2010). Seggenrohrsängernester wurden während der gesamten Brutperiode 2011 in zwei Gebieten des Nemunas Deltas (Sysa und Sausgalviai) und im Tyrai-Moor am Ufer des Kuhrischen Haffs gesucht. Insgesamt wurden 15 Nester gefunden. Zählungen singender Männchen fanden Anfang Juni und Anfang Juli statt. Managementempfehlungen zum Schutz der Seggenrohrsängernester basieren auf der Entfernung der Nester zu den singenden Männchen. Der Mahdfortschritt wurde über die gesamte Brutperiode kartiert. Die Größe der

Fläche, in der Seggenrohrsängernester zu erwarten waren und die im Verlauf der Heuernte gemäht wurde, wurde berechnet.
Vegetationsstrukturparameter mit Einfluss auf die Ansiedlung von Seggenrohrsängern konnten nicht statistisch nachgewiesen werden (Generalized Linear Mixed Models (GLMM)). Die Ursachen sind vermutlich eine zu geringe Anzahl an untersuchten Flächen ohne Seggenrohrsängervorkommen innerhalb des Datensatzes. Der zeitliche und räumliche Maßstab der Untersuchung war vermutlich zu klein. Andere, nicht untersuchte Parameter, wie der Fortschritt der Heuernte oder Nahrungsverfügbarkeit, könnten zudem wesentliche Faktoren für die Verteilung von Seggenrohrsängern gewesen sein. Dennoch zeigen die Daten, dass die Brutgebiete des Seggenrohrsängers im Nemunas Delta zu dem gleichen Lebensraumtyp wie die von regelmäßigen Überflutungen geprägten Seggenwiesen des Unteren Odertals zählen. Hier sind eine niedrige Streuschicht und ein geringer Wasserstand wesentlich für die Nistplatzwahl. Die vom Seggenrohrsänger besiedelten Flächen im Nemunas Delta gehören zu den Flächen mit der höchsten Nährstoffverfügbarkeit unter den bekannten Brutgebieten. Torfmineralisierung eine hohe Nährstoffverfügbarkeit der Flächen mit gleichzeitig hoher Produktivität der Vegetation erhalten. Um Sukzession zu einer für den Seggenrohrsänger ungeeigneten Vegetationsstruktur zu vermeiden, sollten ein früher Mahdbeginn und zwei Schnitte pro Jahr auf von Seggenrohrsängern nicht besiedelten Teilflächen angestrebt werden. Die Wasserstände sollten nicht tief unter die Geländeoberfläche abgesenkt werden.
Daten zur allgemeinen Brutbiologie sind in Übereinstimmung mit Ergebnissen früherer Studien. Der Bruterfolg des Seggenrohrsängers (berechnet nach der Mayfield Methode) im Nemunas Delta ist deutlich geringer als in Gebieten, in denen Landnutzung nur im Rahmen von Schutzmaßnahmen durchgeführt wird. Verluste von Nestern durch Mahd wurden im Nemunas Delta beobachtet. Die Fläche, in der die Nester wahrscheinlich verteilt waren, wurde im Verlaufe der Heuernte stark reduziert. Mahd bedeutet daher eine ernstzunehmende Gefahr für die im Nemunas Delta brütenden Seggenrohrsänger. Mit 1.59 flüggen Jungen pro Nest ist der Bruterfolg der Litauischen Seggenrohrsängerpopulation nicht ausreichend zum Populationserhalt, wenn jedes Weibchen nur ein Gelege bebrüten kann. Das Überleben jedes initiierten Nests sollte daher sichergestellt werden.
Seggenrohrsängernester wurden im Nemunas Delta innerhalb eines Abstandes von 120 m zu dem nächsten singenden Männchen gefunden. Es wird empfohlen, Zählungen singender Männchen Anfang Juni durchzuführen. Um jedes beobachtete Männchen sollte eine Fläche mit einem Radius von 116 m mindestens bis zum 15. August von der Mahd ausgespart werden. So wird der Schutz von frühen und späten Seggenrohrsängerbruten gewährleistet.

1 INTRODUCTION AND AIM OF THE STUDY

The Aquatic Warbler (*Acrocephalus paludicola* Vieillot 1817) used to be a common breeding bird in fen mires dominated by sedges or grasses throughout Europe (Schulze-Hagen 1991, AWCT 1999). During the 20th century numbers of Aquatic Warblers extremely decreased due to large scale drainage and intensification of agriculture within the breeding habitats. Nowadays it is the rarest and only globally threatened passerine bird of mainland Europe with a fragmented breeding distribution (Flade and Lachmann 2008). This has led to increased conservation effort and conservation related research since 1990 (Tanneberger et al. 2008).

A small Aquatic Warbler population breeds in floodplain meadows of the Nemunas delta and at the shore of the Curonian Lagoon in Lithuania. At least since the 1990s the Lithuanian Aquatic Warbler population is declining. Unlike all other known Aquatic Warbler habitats the occupied meadows of the Nemunas delta are agriculturally used for hay harvest.

In order to halt future decline of this Aquatic Warbler population breeding in an agricultural landscape, specific conservation measures based on understanding of this specific populations` habitat requirements are needed. In addition, information on a populations breeding biology and performance are often essential in identifying effective conservation measures for threatened and declining species (Green 2004). It is therefore particularly important to know, if breeding success of the Lithuanian Aquatic Warbler population is sufficiently high to maintain population size. Also better knowledge on the impact of meadow harvest on this populations` breeding success is necessary.

Except of a three years study (2010-2012) in the Biebrza marshes in northeast Poland (Kubacka et al. unpublished), all recent studies on Aquatic Warblers breeding biology have been carried out in the large core populations habitats, where management was limited or absent, i.e. the large mires of Poland and Belarus (Dyrcz and Zdunek 1993b, Kozulin and Vergeichik 2006, Vergeichik and Kozulin 2006a, Vergeichik and Kozulin 2006b).

Aquatic Warbler habitat selection has been well studied, also in the management dependent habitats of the endangered ´Pomeranian population` (Tanneberger et al. 2008, Tanneberger et al. 2009, Tanneberger et al. 2010).

Nevertheless, only few scientific data are available (Tanneberger et al. 2010) on the Lithuanian Aquatic Warbler population breeding in agriculturally used habitats. Thus the aim of this study to complement existing knowledge on Aquatic Warblers breeding biology and habitat selection with new findings from the Lithuanian Aquatic Warbler population. Management recommendations are given in order to contribute to the protection of this declining population. Requirements of Aquatic Warblers breeding in the meadows mown for hay harvest shall be combined with agricultural needs, if possible.

Therefore the following fields of research were addressed :

I. Habitat selection

Previously several parameters have been identified as being crucial for the occurrence of Aquatic Warblers (Leisler 1981, Schulze-Hagen 1991, Dyrcz and Zdunek 1993a, Kozulin and Flade 1999, Tanneberger et al. 2008, Tanneberger et al. 2009, Tanneberger et al. 2010).
It was tested whether these parameters also apply for the small Lithuanian population.

II. General breeding biology, breeding success and meadow harvest

Research on general breeding biology and an analysis of breeding success of Aquatic Warblers in the major breeding habitats in Lithuania was carried out. It was investigated whether breeding success of Aquatic Warblers breeding in the agriculturally used Nemunas delta differs from breeding success in the agriculturally unused habitats. Additionally the area, where Aquatic Warbler nests were expected to be located, was identified. A monitoring of meadow harvest was carried out and this areas proportion lost due to mowing in 2011 was calculated.

III. Management recommendations

Meadow harvest in the Nemunas delta usually starts in the beginning of June and lasts at least until the middle of August. The exact onset and progress of meadow harvest so far is not adjusted to the occurrence and timing of breeding of Aquatic Warblers.
Influencing timing, frequency and technique of land-use is a common tool to reduce loss of clutches and nestlings of ground-nesting grassland bird species (Hötker 1991, Fischer et al. 2012). For several meadow bird species (e.g. Yellow Wagtail *Motacilla flava*, Whinchat *Saxicola rubetra* and Corncrakes *Crex crex*) delayed mowing dates have been recommended in particular breeding areas (e.g. Heer et al. 2000, Bellebaum et al. 2002, Broyer 2009, Fischer et al. 2012). Other studies reported that permanent late mowing proved to be an inappropriate management tool for Aquatic Warbler habitats (Tanneberger et al.

2008). Additionally management schemes based upon delayed mowing dates are rather unpopular for farmers economically depending on the meadow harvest (Schäffer and Weisser 1996), as is the case in the Nemunas delta. If permanent late mowing in order to protect meadow bird populations is not feasible, several authors propose the protection of single nests (Kruk et al. 1996) or mowing regimes adjusted to the distribution of the birds (Schäffer and Weisser 1996, Heer et al. 2000, Tyler et al. 1998).

The search for Aquatic Warbler nests is invasive and time-consuming, thus not feasible within usual conservation management. As previous studies showed, singing male surveys can be used as indicators for the current distribution of Aquatic Warbler nests (Schulze-Hagen 1999, Dyrcz & Zdunek 1993 a, Kubacka et al. unpublished). Therefore the utilisation of records of singing males to identify the area where Aquatic Warbler nests most likely are located is proposed. With sparing this area from mowing a majority of Aquatic Warbler nests will be protected. In addition findings on site conditions of the Aquatic Warbler habitat in the Nemunas delta were used to develop adequate management recommendations for maintaining habitat quality suitable for the Aquatic Warbler.

2 STUDY SPECIES AND STUDY REGION

2.1 The Aquatic Warbler

2.1.1 Species characteristics

The Aquatic Warbler, belonging to the Sylviidae warblers, is a small passerine bird (length 13 cm, weight 10.0-14.5g) (Wawrzyniak and Sohns 1977) wintering in tropical West Africa and breeding in wetlands mainly in Europe (Schulze-Hagen 1991).
Morphological adaptations enable the Aquatic Warbler to climb in slender grassy vegetation (Schulze-Hagen1991). In contrast to other *Acrocephalus* species the bill is strong and large (Schulze-Hagen1991), allowing the collection of large prey items (Wawrzyniak and Sohns 1977, Schulze-Hagen et al. 1999). The species forages mostly on large arthropods of fen mires: Arachnida, Diptera, Lepidoptera (often caterpillars) and Trichoptera (Schulze-Hagen et al. 1989).
The Aquatic Warbler is a habitat specialist (Leisler 1981, Schulze-Hagen 1991). The species has evolved behavioural and morphological adaptations which enable it to occupy an extreme ecological niche for *Acrocephalus* warblers: large, treeless and homogeneous structured sedge fen mires and similarly structured wetland habitats with a water depth of 1-10 cm (Schulze-Hagen 1991, AWCT 1999, Tanneberger 2008). In primeval landscapes it probably occurred in mesotrophic or slightly eutrophic floodplain fen mires which do not overgrow with trees due to regular flooding and the surface oscillating with the water table (AWCT 1999).
Nowadays Aquatic Warblers have been recorded in a few habitat types, all depending on more or less intensive management (Flade and Lachmann 2008, Tanneberger 2008). These are, amongst others, mesotrophic, slightly eutrophic open sedge fen mires in Poland (Biebrza marshes) and Belarus (Dikoe, Zvanets, Yaselda) (Kozulin and Flade 1999, Vergeichik and Kozulin 2006b) and seasonally flooded meadows in Poland (islands in Swina river mouth), Germany (Oder Valley) and Lithuania (in the Nemunas delta and at the shore of the Curonian Lagoon) (Tanneberger et al. 2008, Tanneberger et al. 2010).
The Aquatic Warbler is a long distance migrant. During migration it favours low stands of sedges and reeds near open water (De By 1990). The wintering habitats are large, water-logged and open grassy marshes of *Scirpus littoralis*, *Oryza barthii*, *Eleocharis mutata* and

Sporobulus robustus in sub-Sahara Africa (Flade et al. 2011).

The species mating system is between promiscuity and polygyny (Schulze-Hagen 1999) and unique compared to the breeding systems of all other *Acrocephalus* species (Dyrcz and Zdunek 1993a). Since females raise broods alone and males are emancipated from parental care (Dyrcz and Zdunek 1993a, Giessing 2002), the high abundance of food in the sedge fen mires and the possibility of feeding nestlings with relatively large prey items are essential (Schulze-Hagen et al. 1989, Dyrcz and Zdunek 1993a). Females usually raise two broods between May and August (Wawrzyniak and Sohns 1977, Dyrcz and Zdunek 1993a). Nests are built near the soil surface (Schulze-Hagen 1991) and foraging areas of females do not overlap (Dyrcz and Zdunek 1993a, Schulze-Hagen 1999).

Males do not defend territories, their home ranges of 4.6 ha (core areas 0.11 ha) overlap widely and they change territories during the breeding season (Schulze-Hagen 1999, Schaefer et al. 2002). During incubation and breeding females use home ranges of about 1.6 ha (Schaefer et al. 2002).

2.1.2 Distribution, population trend and habitat loss

Currently the Aquatic Warbler is the rarest and only globally threatened passerine bird of mainland Europe (Flade and Lachmann 2008). The species is listed as vulnerable in the IUCN Red List of Globally Threatened Species because of its rapid decline in the past and the current very limited area of occupancy of <1.500 km^2 (Flade and Lachmann 2008, BirdLife International 2012). It is included in several international conventions and agreements, e.g. Annex I of the EU birds directive (2009/147/EG) and a Memorandum of Understanding concerning the conservation of the Aquatic Warbler, which was signed under the Convention on Migratory Species (CMS) (Bonn Convention).

The Aquatic Warbler used to be an abundant breeding bird throughout Europe (Schulze-Hagen 1991). During the 20^{th} century over the whole of Europe about 60% of mires have been artificially drained (Joosten and Clarke 2002), resulting in large scale-loss of area suitable for the species (Flade and Lachmann 2008). Additionally the cessation of traditional land use, such as low intensity hay harvest or grazing, lead to the overgrowth of fens and floodplains with bushes or reeds and therefore to the deterioration of Aquatic Warbler habitats (Tanneberger et al. 2008, Lachmann et al. 2010). Therefore today the Aquatic Warbler depends on management in most of its breeding grounds (Tanneberger et al. 2008).

The current world population is estimated at 11.000-16.000 singing males (BirdLife International 2012). The major Aquatic Warbler populations breed in Poland, Belarus and

Ukraine. Additionally regular breeding occurs in Lithuania, and until recently in Germany and Hungary (Flade and Lachmann 2008, BirdLife International 2012) (Fig. 1).
Known wintering sites are located in Senegal, Mauritania and the inner Niger Delta (Flade et al. 2011, BirdLife International 2012). Here changes in hydrology and land-use threaten habitat suitability as well (Flade et al. 2011).

The Lithuanian Aquatic Warbler population

During the first half of the 20th century the Aquatic Warbler has been described as a common bird breeding in large sedge meadows at the eastern shore of the Curonian Lagoon. The Nemunas delta was referred to as the only large Aquatic Warbler breeding area in former Eastern Prussia (Tischler 1941).
At present the Lithuanian Aquatic Warbler population is declining (BirdLife International 2012). The species is listed as vulnerable in Red Data book of Lithuania (category II). In 2000 still a population size of 223-247 Aquatic Warbler singing males was estimated for the whole country (LOD 2000). In 2012 only 64 singing males were counted (data from BEF, unpublished) (for numbers of Aquatic Warbler singing males for the separate breeding areas see Tab. 1).

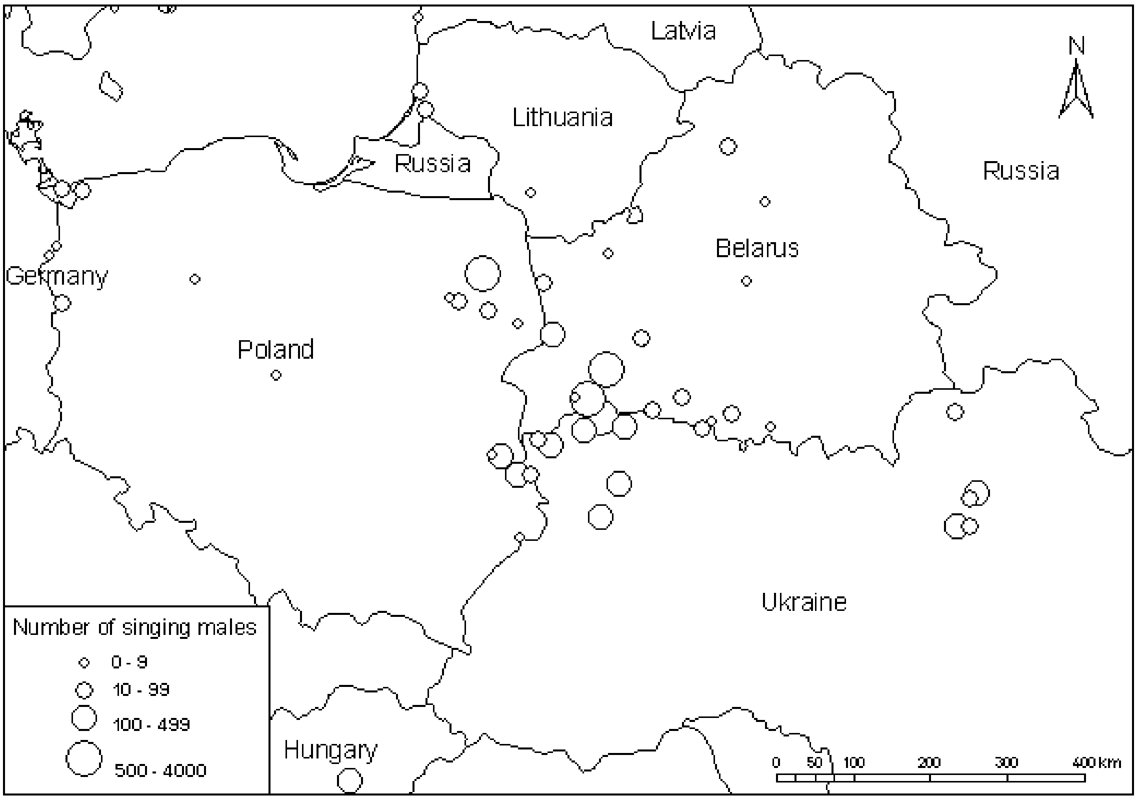

Fig. 1. Breeding sites of the Aquatic Warbler in 2010 (from AWCT 2011, modified).

Tab. 1. Numbers of Aquatic Warbler singing males in Lithuanian breeding areas.

year	Tyrai mire	Sysa	Sausgalviai	Zuvintas
1990s	-	-	-	10
1994	250-300	-	-	-
2000	190-210	-	10 [a]	-
2004	110-130	100-110	-	-
2006	-	45-55	5-9	-
2008	56-70	35-35	6-7 [b]	-
2011	30-45	23-30	12-11 [c]	1-1
2012	28-29	22-13	3-5	0-1

Data from BEF, except indicated elsewise:
[a] LOD 2000, [b] data from Nemunas delta Regional Park, [c] own data.

2.2 Study region

The study was conducted in the delta of the Nemunas river, located in the southwestern part of Lithuania, near the town Silute. The region is bordered to the south by Kaliningrad Oblast (Russian Federation) and to the west by the the Curonian Lagoon, which is separated from the Baltic Sea by the Curonian Spit (Fig. 2). Near the small town Priekule Tyrai mire is located at the shore of the Curonian Lagoon.

The climate is moderately continental and influenced by the Baltic Sea (Neef 1982). Mild western winds prevail at the coast (Svazas et al. 1999). The mean annual temperature is 7 ºC. With a mean temperature of 16.8 ºC July is the warmest month. January is the coldest month with a mean temperature of -2.6 ºC (Svazas et al. 1999). The mean annual precipitation is 700-750 mm. The month with highest precipitation is September (75-85 mm). Precipitation is lowest in March (35-40 mm) (Nemunodelta 2012).

The study region is situated in the western part of the East European Plain (Neef 1981). The surface of the Nemunas river delta lowland is flat and was formed during the last glacial period (Svazas et al. 1999). The brackish adjacent Curonian Lagoon was formed in the early post-glacial period, about 7.000 years ago, when the sandy Curonian Spit separated the shallow bay from the Baltic Sea. In the northern part the Lagoon is connected with the sea through the narrow Klaipeda strait (Svazas et al. 1999). The Nemunas delta has been affected by eight Holocene marine transgressions, each accumulating marine sediments (Kunskas 1982). Currently the elevation of the study areas is slightly above sea level (Sysa

0.2 m, Tyrai 0.2 m) (data from BEF, unpublished). The Nemunas delta is situated in an area with future sinking of the coast relative to sea level (Eronen et al. 2001).

The Nemunas is one of the biggest rivers in Lithuania, with a total length of 937 km (Svazas et al. 1999). It flows into the Curonian lagoon near the town Silute, forming a wide delta, intersected by numerous small streams and canals. The whole area is characterised by extensive areas of wetland habitats (Svazas et al. 1999). Weber (1902) and Fleischer (1882) mention a concentration of fens in the Nemunas delta. Western winds from the Curonian Lagoon cause annual flooding of the coastal meadows during winter and spring. Spring floods last from 57-62 days with water levels rising up to 2-3 m. Flood control is performed by a large system of polders and dams. Soils in the Nemunas delta are fertile due to accumulation of alluvial deposits (Svazas et al. 1999).

Fig. 2. Location of the study region (black square).

3 METHODS

3.1 Study sites

Study sites were located in the floodplain polders of Sysa (55°18'50.3" N, 21°25'23.8" E, study area: c. 260 ha) and Sausgalviai (55°16'47.1" N, 21°27'46.0" E, study area: c. 73 ha), in the Nemunas delta (Fig. 3). The vegetation is dominated by sedges (mainly *Carex gracilis* and *Carex disticha*) and grasses (mainly *Phalaris arundinacea*). The open structure of meadows is maintained by mowing and grazing. Large parts of the meadows are privately owned (approximately 70 landowners in Sysa). Water is pumped out of the meadows after the spring floods (Raudonikis 2004) and meadow harvest usually starts in the beginning of June (Z. Preizka pers. comm., own observations). Both study areas are to a large extent subdivided into subunits surrounded by ditches or roads. Each of these subunits is hereafter referred to as a site. The Aquatic Warbler breeding areas in the Nemunas delta are Special Protection Areas (SPA) as part of the NATURA 2000 network and belong to the Nemunas Delta Regional Park (Svazas et al. 1999).

Tyrai mire (55°31'47.3" N, 21°13'35.8" E) is a floodplain mire at the shore of the Curonian Lagoon (Fig. 3). Aquatic Warblers occur in the southern part of the mire, dominated by sedges (mainly *C. disticha*). The large northern part of the mire currently is overgrown by reeds (*Phragmites australis*), since winter reed cutting was ceased in recent decades (A. Pranaitis pers. comm.). During the first half of the 20th century the mire was used for military purposes and artificially drained (LOD 2000), still visible by overgrown drainage ditches (mainly with *Glyceria maxima*). Pumping of the meadows stopped in the middle of the 20th century and the area was preserved from further drainage and intensive agricultural use (Z. Preizka pers. comm.). Today Tyrai mire is protected within the Kiliosai Landscape Reserve (LOD 2000).
The study areas are the major Aquatic Warbler breeding areas in Lithuania.

3.2 Fieldwork

Fieldwork was conducted during the Aquatic Warbler breeding season in 2011, starting in the middle of May and lasting until the middle of August.

For the study on Aquatic Warbler habitat selection additionally data collected in 2006 in the Nemunas delta (Sysa, Sausgalviai, Rusne, Minija, Sakuciai) and in Svencele (data from

Tanneberger et al. 2010) were included into the analysis (Fig. 3).

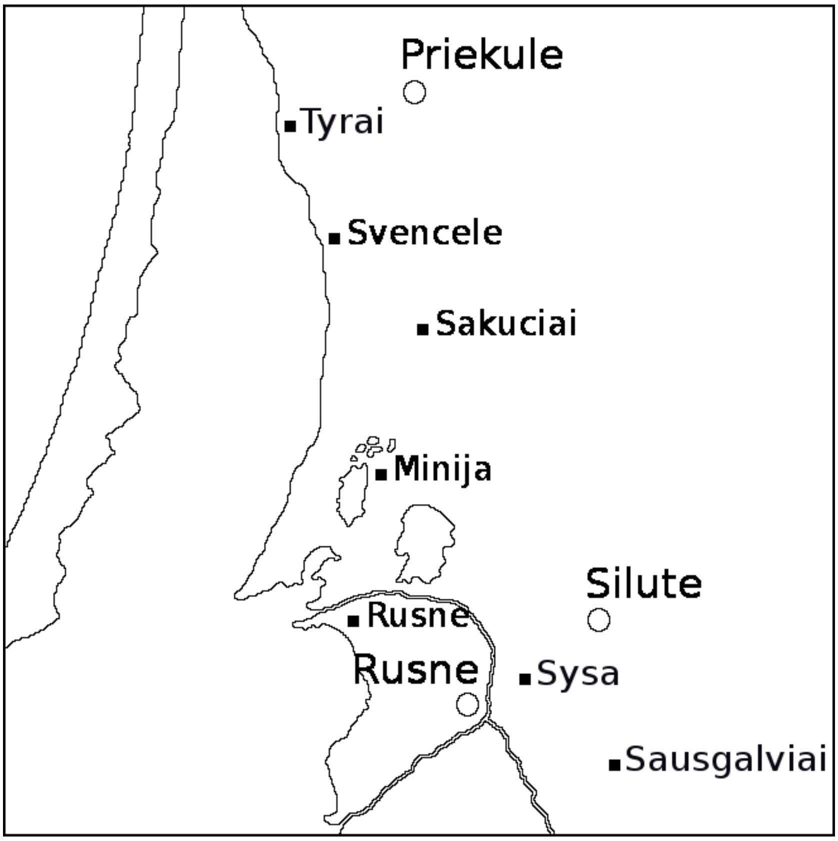

Fig. 3. Location of areas studied in 2006 and 2011.

3.2.1 Habitat data

In order to allow a combined analysis of the habitat data collected during the field season in 2011 with data collected in 2006, field methods were chosen according to methods applied in 2006 (following Tanneberger et al. 2008, Tanneberger et al. 2010). Habitat data in 2011 were collected at the peak of the first brood of Aquatic Warblers (late May/ early June), at the peak of the second brood (late June/ early July) and some vegetation plots were sampled again in late July/ early August to evaluate whether the influence of some parameters on Aquatic Warbler habitat selection changed across the breeding season. In 2006 habitat data were collected once in late May/ early June. Only if the vegetation structure within one site differed markedly thus possibly affecting habitat suitability, more than one vegetation plot was installed. The overall numbers of studied subunits (sites) per study area and sampled vegetation plots per site are presented in Tab. 2.

Tab. 2. Characteristics of the Lithuanian Aquatic Warbler breeding areas. (Table from Tanneberger et al. 2010, partly modified based on own data).

name of area	location of site	main soil type	dominant plant species	Aquatic Warbler population 2006	number of sites/ plots per study area 2006	number of sites/ plots per study area 2011
Sysa	polder area in Nemunas delta (with dikes)	peat	sedge	50-60	18/ 21	24/ 28
Sausgalviai	polder area in Nemunas delta (with dikes)	peat	sedge	14	18/ 20	2/ 7
Rusne	island in Nemunas delta (with dikes)	peat	sedge	2	12/ 13	0
Minija	ox-bow in Nemunas delta	peat	sedge	0	6/ 6	0
Sakuciai	polder area in Nemunas delta (with dikes)	peat	sedge	0	3/ 3	0
Svencele	Curonian lagoon shore (partly with dikes)	peat	sedge	6	2/ 2	0
Tyrai	Curonian lagoon shore	peat	sedge, reed	NA	0	2/ 3

Habitat data are from Tanneberger et al. 2010 and own data, Aquatic Warbler data are from Tanneberger et al. 2010. NA: result of Aquatic Warbler count was not available.

Each vegetation sample consisted of a plot of $25m^2$ (5x5m) with three randomly distributed 1x1m sub-plots within the larger plot (Fig. 4). Plots were marked in the field with wooden sticks and coordinates were recorded using a GPS (Garmin etrex legend HCx). Vegetation plots were installed on sites with observed singing males in the year of the study (occupied sites/ presence sites) and on sites where Aquatic Warbler singing males were not recorded in the year of the study (absence sites).

The occurrence of Aquatic Warblers within a study area was defined by at least one individual singing male being recorded during the particular study period within at least one of the studied sites per area.

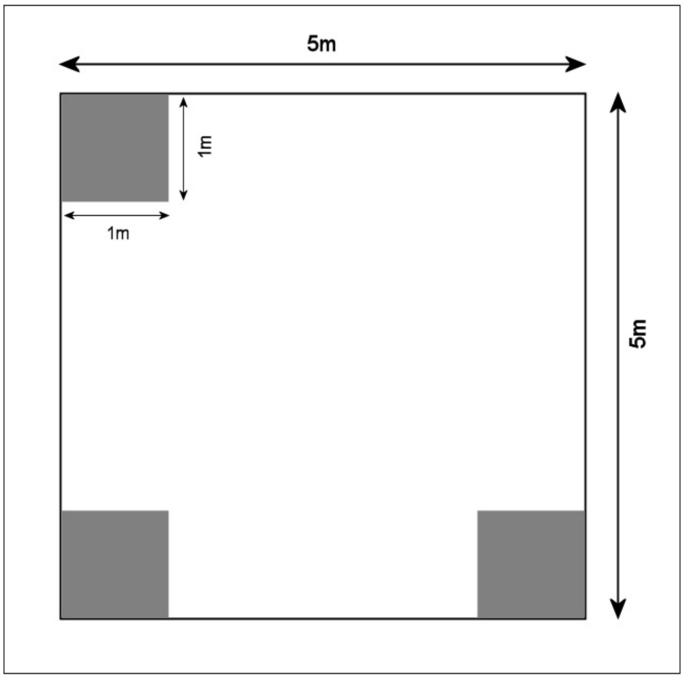

Fig. 4. Schematic illustration of a 25m^2-vegetation plot with three 1m^2-subplots.

As previous studies have shown, habitat choice of Aquatic Warblers is influenced by vegetation structure rather than plant species composition. Thus parameter sampling and analysis focused on vegetation structure variables, that formerly have been identified as essential in Aquatic Warblers habitat selection (Leisler 1981, Schulze-Hagen 1991, Kozulin and Flade 1999, Tanneberger et al. 2008, Tanneberger et al. 2010), namely: vegetation height, soil moisture/ water level (Leisler 1981, Schulze-Hagen 1991, Kozulin and Flade 1999), the thickness of the litter layer and the cover of lower (<30cm; K1) and upper (>30cm; K2) herb layer (Tanneberger et al. 2008, Tanneberger et al. 2010) and the total plant species number per plot.

Vegetation height and litter height were measured with a measuring stick, measuring the highest stalk next to the stick, 12 times per plot (4 times randomly in each of the three sub-plots) and expressed in centimetre above soil surface. For water height the same amount of measurements was taken. Plant species cover (lower and upper herb layer, moss layer) and the cover of the litter layer were estimated in Londo scale as the proportion of ground covered and transformed into percentages (Londo 1976, see Annex 1). Coverage of open water and bare soil were estimated in Londo scale as well.

Soil moisture was estimated in six classes: dry, fresh, moist, moist-wet, wet, open water expanse (after AG Boden 2005).

Soil samples were taken using three samples of 5-10 cm depth per plot (n=19 in 2011, n=47 in 2006) (cf. Succow and Joosten 2001). In 2011 soil samples were mainly collected on sites that had not been sampled in 2006. Samples were stored in polyethylene bags in a refrigerator during field stay and afterwards analysed in the Botanical Institute of Greifswald University. Root mass was removed from samples before drying them in an oven for 24 hours at approximately 100°C with subsequent grinding (Pulverisette 14 Fritsch Idar-Oberstein; mesh size 0.2mm). The carbon-nitrogen-ratios (C/N ratios) were measured by DUMAS digestion with a C/N-analyser (Element vario EL, elementar Analysensysteme Hanau) in order to identify the trophic classes of the sites. Samples were weighed into tin foil and dried again for one hour at 80°C.
Furthermore soil samples taken in 2011 were analysed for organic matter content. The organic matter content (loss on ignition) was determined by glowing dried samples at 550°C in a muffle furnace for 12 hours. Thereby only organic carbon is oxidised, whereas inorganic carbon remains.

3.2.2 Nest data

Nests were searched for from May 20th onwards, when first Aquatic Warblers nests are about to be active (Dyrcz and Zdunek 1993a), until the 10th of August to assure that also late nests were found. The study design was developed according to the work of A. Dyrcz (Dyrcz and Zdunek 1993a, Dyrcz and Zdunek 1993b) and L. Vergeichik and A. Kozulin (Kozulin and Vergeichik 2006, Vergeichik and Kozulin 2006a).

Aquatic Warbler nests are found via the detection of Aquatic Warbler females. Females in this species behave cryptic and shy and are difficult to observe (Schulze-Hagen 1995, Schulze-Hagen 1999). They stay in the vicinity of the nests throughout the nesting season and indicate its presence by warning calls (Wawrzyniak and Sohns 1977, Schulze-Hagen 1999). In the early nest-stage warning calls are rather low and only increase in frequency and intensity later during the nesting period (Schulze-Hagen 1999). Thus females are more likely to be detected whilst nests are in the nestling-stage. Females were searched for in all sites where singing males were detected and in nearby sites with the attempt to cover as much area as possible (due to the low density of Aquatic Warblers in Lithuania using fixed study plots as known from other studies, e.g. Dyrcz and Zdunek 1993a, was not feasible). One or two persons were walking with constant speed systematically in loops across sites, trying to spot the females optically or acoustically. Study sites recieved equal search effort and were searched for in equal intervals across the whole breeding season.

Females were constantly observed in order to find their nests. Thereby a distance, that did not disturb the bird (20-60m) was kept, indicated by absence of warning calls. At the spot where the female seemed to take off from or arrive at the nest either for incubation or to feed her young (Dyrcz and Zdunek 1993b), the vegetation was carefully searched for the nest. Caution was taken to produce as few tracks as possible in the nest vicinity, in order to avoid leading predators to the nest.

Nests were marked in the field by ribbons within a distance of a few meter from the nest. Another hidden ribbon was tightened to the vegetation near the nest indicating the exact location. Nest coordinates were recorded with a GPS (Garmin etrex legend HCx) and the number of eggs or chicks as well as the age of chicks were recorded (cf. Wawrzyniak and Sohns 1977).

Nests were checked in intervals of three or four days in order to detect the exact hatching-date and/ or the fledging-date of nestlings. It was attempted to visit each nest when nestlings were assumed to be 14 days old, i.e. when they should be ready to fledge (Wawrzyniak and Sohns 1977). Since only few nests were found in the egg-stage, it was assumed that all nests were complete at the stage they were found. A nest that was found destroyed or empty at least 3 days before the estimated fledging date was considered as not being successful. A nest was considered as being successful when it was found empty on the day nestlings were predicted to reach an age of 14 days or later.

in a 1x1m^2-plot at the nest, six measurements each of litter height, vegetation height and the height of the upper nest edge were taken with a folding stick, expressed in cm above soil surface and averaged for nest-site description. Soil moisture was estimated in six classes (cf. AG Boden 2005). The cover of lower and upper herb layer, the cover of litter layer, open water and open soil surface were estimated and the number of plant species was recorded at the nest. The proportion of ground covered was estimated using the Londo scale and transformed into percentages (Londo 1976). The dominant plant species at the nest site was determined (following Jäger and Werner 2002).

3.2.3 Nest area and monitoring of meadow harvest

Three counts of Aquatic Warbler singing males were carried out within this study. Once in the beginning of June (1st count), when singing males are usually counted for the first time within each breeding season in Lithuania. The designation of meadows for the protection of Aquatic

Warbler broods will most likely be based on this first survey. An additional count was carried out within the first half of June (2nd count) to examine whether the distribution of Aquatic Warblers would be the same than in the first count. A third count was conducted in July (3rd count), when late nests of Aquatic Warblers are expected to be active. Findings from the July-count were used to evaluate whether late nests would also be well protected by one designation of meadows to be spared from mowing in the beginning of June.
Surveys of singing males were carried out in the evening at dusk, starting approximately two hours before sunset, when daily singing activity reaches a maximum (Dyrcz and Zdunek 1993a, Schulze-Hagen et al. 1999). Two persons were walking simultaneously on parallel transects across each sampled meadow (cf. Dyrcz and Zdunek 1993a) recording each individual singing male with a GPS (Garmin etrex legend HCx).

The progress of the meadow harvest was monitored every 1 to 5 days. Exact corner points of mown meadows were recorded with a GPS. The recorded dates of meadow harvest were grouped in intervals of two weeks (cf. Bellebaum et al. 2002): before 15.06.11, 16.-30.6.11, 1.-15.7.11, 16.-31.7.11. and 1.-15.08.11. Results were analysed and visualised using a GIS-software.

3.3 Data analysis

3.3.1 Habitat data

Univariate statistics

Parameters that previously have been identified as being crucial in Aquatic Warbler habitat selection were tested for differences between occupied sites and sites where Aquatic Warblers were absent. Therefore the non-parametric Mann-Whitney U-test was calculated. Non-parametric Kruskal-Wallis-test with Holm correction for multiple comparisons (Crawley 2007) was used to test for differences in C/N-values and OM content of different study areas.

Multivariate statistics

Several sites sampled 2006 have been sampled again in 2011. Thus data form part of a time series or are grouped in one place. They are not independent from each other and are pseudoreplicated (Hurlbert 1984, Crawley 2007). The appropriate choice of statistical analysis has to be a model that includes the effect of pseudoreplication for not obtaining false significant results (Crawley 2007).

To answer the question which parameters affect habitat selection of Aquatic Warbler males, only the information about Aquatic Warbler's occurrence was relevant. Count data of Aquatic Warbler singing males were transformed to presence-absence data (Leyer and Wesche 2007), which lead to a binary response variable with non-normally distributed errors.

Generalized Linear Mixed Models (GLMM) can deal with non-normally distributed errors, in this case binomial error distribution, and incorporate the effect of pseudoreplication via the random effect term and hence were selected for the analysis (Crawley 2007).

Candidate predictor variables were chosen to a priori considerations with reference to existing knowledge about Aquatic Warbler habitat selection (following Whittingham et al. 2006).

The candidate set of predictor variables consisted of vegetation height, litter height, soil moisture and water level. Either plant species number per plot or the cover of the lower herb layer were included into the models, since both parameters reflect the occurrence of CSR species, which mostly occur in the lower herb layer and mostly cause a higher species number per plot. CSR species are species of the intermediate strategy type with a combination of competition, stress and ruderal strategies (Grime 1974), that are characteristic of meadow and low meadow vegetation and indicate a sparser growth of highly competitive species such as reed or tall grasses (Tanneberger et al. 2008). The predictor variables reflecting the occurrence of CSR species were included, because Aquatic Warbler seem to avoid dense and tall stands of reed or tall grasses (Tanneberger et al. 2008, Tanneberger et al. 2010).

Additionally the cover of the upper herb layer, the cover of the litter layer, cover of bare soil and cover of open water were included into the candidate set of predictor variables.

All coverages were the estimates of coverage of the $25m^{2-}$plot and all measurements were the averaged measurements of the three randomly distributed sub-plots per plot.

Predictor variables were tested for correlation. Variables that met or exceeded Spearman rank correlation coefficients of 0.7 were not combined within one of the candidate models (following Green 1979, Fielding and Haworth 1995).

Within models with several predictor variables the effects of these variables can interact, i.e. the effect of one predictor depends on the effect of another predictor variable (Leyer and Wesche 2007). For the available data set models with several interaction terms did not converge, most probably due to the rather small sample size. Therefore only biologically plausible and for the occurrence of Aquatic Warblers relevant interaction-terms were chosen.

The interaction terms day:vegetation height, day:upper herb cover and day:water height were incorporated into the models analysing the complete dataset to examine whether the influence of these predictors change across the different periods of data-sampling.

Year, area and sampling site were included into the model as random effects in order to accommodate for spatial and temporal pseudoreplication.

The presence or absence of Aquatic Warbler singing males was chosen as response variable for the models.

Models were run for two datasets:

1. The reduced dataset, including only data collected in late May/ early June 2006 and 2011, was used to identify parameters influencing Aquatic Warblers habitat selection in the beginning of the breeding season.
2. The complete dataset was used to identify parameters crucial for Aquatic Warbler habitat selection across the whole breeding season. Therefore the day of the season was additionally included as a covariate into the model.

Several biologically plausible multivariate candidate models were constructed (see Annex 12 & 13). Univariate models for the candidate predictor variables were run in order to evaluate the weight of the different predictors in the data. An intercept-only model (a model without a fixed effect term) was calculated for both data sets to test whether any of the tested parameters would explain the occurrence of Aquatic Warblers (following Burnham and Anderson 2002).

An information-theoretic approach for inference was used to select the best models out of a set of candidate models. Support for each model was evaluated using AIC (Akaike`s Information Criterion, Akaike 1974) as a criterion for measuring the relative goodness of fit of a statistical model (Burnham and Anderson 2002, Whittingham et al. 2006). Therefore models were ranked according to their AIC-values and ΔAIC-values (the difference in AIC between a selected model *i* to the model with the lowest AIC) were calculated. Burnham and Anderson (2002) suggest proceeding as follows: if $\Delta AIC < 2$, it can be assumed that both models are approximately equally supported by the data. If ΔAIC would be $2 < \Delta AIC < 7$, it can be assumed, that there is a difference in the models. If ΔAIC would be ≥ 7, the conclusion that there is a real difference between the models is supported (Burnham and Anderson 2002). Additionally Akaike weights ωi (ωAIC) representing the relative probability of a model out of a model set, were used to evaluate the effect of predictor variables. The bigger the ωAIC value of a model *i*, the bigger is the weight (Burnham and Anderson 2002). The bigger the cumulative ωAIC for all the models including a certain predictor variable, the bigger is the predictor variables' effect (Burnham and Anderson 2002, Whittingham et al. 2006).

Using this approach statistical inference can be based on a set of models (multi-model inference) instead on a selected single best model (Anderson and Burnham 2002).

3.3.2 Nest data

The traditional way to present nest success is to present the proportion of successful nests among all nests irrespectively of the stage at which they were found, termed ´apparent nest success` (Mayfield 1975, Dyrcz and Zdunek 1993b). As Mayfield pointed out, this estimate of nest success is only appropriate if destroyed nests can be found with the same probability as active ones (Mayfield 1975). Since, most likely, not all nests are found at an early stage (e.g. the egg-laying period) and some unsuccessful nests might not be found at all, the use of the ´traditional way` of estimating nest success would result in biased estimates (Mayfield 1975).
Nest survival (or nest success), defined as the probability that a nest will be successful, according to the Mayfield method is calculated on the basis of the number of unsuccessful

nests in the sample and on the exposure days, which is the cumulative number of days the nests were monitored (Dinsmore et al. 2002). Daily nest survival rate (or daily survival rate) is estimated as 1 - [(number of nest losses)/(total exposure days)] and defined as the probability that a nest will survive a single day. Nest survival then is calculated as (daily nest survival rate)^n, where *n* is the length of the nesting period (incubation + nestling period) (Dinsmore et al. 2002), which is 28 days in the Aquatic Warbler (14 days for incubation + 14 days for nestling period) (Wawrzyniak and Sohns 1977).

For obtaining information on Aquatic Warbler reproductive success in Lithuania in Nemunas delta and Tyrai mire nest survival was estimated according to the Mayfield method and breeding success was calculated. Breeding success, defined as the resulting fledglings per nest, was calculated by multiplying nest survival with the average number of fledglings per successful nest (Dyrcz and Zdunek 1993b). Two competing models were constructed, the first model estimating nest survival probabilities for the entire dataset obtained in Lithuania in 2011. A second model estimated separate probabilities for the Nemunas delta and Tyrai mire. The support for each of these models was evaluated using AICc and Δ AICc (Burnham and Anderson 2002).

Additionally the proportion of successful nests over all nests (´apparent or traditional nest success`) is presented for comparison with older studies that did not estimate daily survival probabilities (e.g. Dyrcz and Zdunek 1993b).

For descriptive presentation of parameters measured at the nest, mean and standard deviation (or median and median absolute deviation respectively) and minimum and maximum values are given. Data were log-transformed and t-test was calculated to test for differences in clutch sizes between early and late nests.

3.3.3 Nest area and monitoring of meadow harvest

Buffers were set around singing males in a GIS, that were expected to include the majority of nests. Therefore distances between Aquatic Warbler nests and the nearest singing male (hereafter referred to as nest-male distances) were calculated for two datasets:

- nests found in the Nemunas delta (Sysa and Sausgalviai) in 2011 (n = 8)
- nests found in the Biebrza marshes, eastern Poland, in 2011 (n = 156) (unpublished data from OTOP).

90% and 95% percentiles of the distances between Aquatic Warbler singing males and nests for both datasets were calculated, assuming that a nest buffer derived by the 90% and 95% percentiles would enclose 90% and 95% respectively of Aquatic Warbler nests. It was evaluated whether data obtained from the large population in the Biebrza marshes can be transferred to the small Lithuanian population in order to give recommendations for protection-management. Mann-Whitney U-test was calculated to test whether nest-male distances in the Nemunas delta and in the Biebrza marshes differ significantly.

Nests can be located in any direction of a singing male. Thus nest-male distances were treated as the radius of a circle whilst setting nest buffers. Buffers were combined and the complete nest area for the first singing males count was calculated. Additional nest area derived from later counts was added in order to derive a total nest area for all three counts. The nest areas proportion derived from second and third count of the total nest area was treated as an estimate of loss of nest area, if parts of meadows to be spared from mowing were only designated based on the first singing male survey in the beginning of June.

Nest area sometimes extended into meadows without any observation of Aquatic Warbler singing males. This areas percentage of the total nest area was calculated and treated as an estimate of loss of nest area, if only parts of meadows with current records of singing males would have been spared from mowing.

Nest area was layered with the mowing progress and loss of nest area per interval was calculated.

3.4 Software

Data management has been carried out with Open Office 2.0. Statistical analysis were conducted with R 2.10.1 (R Development Core Team). The package ´lme4` was used to compute Mixed Models. Nest survival analysis was carried out with Program MARK (White and Burnham 1999). The Aquatic Warbler nest area was calculated and the monitoring of meadow harvest was analysed with Quantum GIS (Q GIS Version 1.7.4-Wroclaw) (Quantum GIS Development Team 2012). Maps were produced with Q GIS Version 1.7.4-Wroclaw and ArcGis 10. Boxplots were generated with R 2.10.1, charts and diagrams with Open Office 2.0.

4 RESULTS

4.1 Aquatic Warbler habitat

4.1.1 Aquatic Warbler occurrence in relation to vegetation structure

In 2006 and 2011 Aquatic Warblers occurred in five out of seven areas (Sysa, Sausgalviai, Rusne, Svencele, Tyrai) (Tab.2, Annex 2).

Aquatic Warblers occurred in late May/ early June on sites, where soil was moist or moist-wet. Open water expanses were hardly found on occupied sites (median ± MAD 0.5 ± 0.7%) (Tab. 3). Vegetation height was only slightly lower on current sites (median ± MAD 46.67 ± 10.2 cm) than on sites where Aquatic Warblers were absent (median ± MAD 53.54 ± 13.9 cm), not differing significantly (Tab. 3). In late June vegetation height on current sites was slightly lower than 1m (median ± MAD 95.92 ± 10.63 cm). The thickness of the litter layer was 8.82 ± 9.22 cm (median ± MAD) and was not much different from sites without Aquatic Warblers (Tab. 3). Also the number of plant species per plot, the cover of the upper herb layer (median ± MAD 63.3 ± 19.8% in current sites), the cover of the lower herb layer (median ± MAD 8.0 ± 10.8% in current sites) and the C/N-ratio (13.6 ± 1.78) did not differ significantly between occupied sites and sites without Aquatic Warbler records (Tab. 3).

Tab. 3. Overview of predictors recorded in late May/early June 2006 and 2011 in Lithuania to explain Aquatic Warbler occurrence.

		Sites Lithuania		
Variable	Unit/ Categories	absence	presence	p-value
		41	43	
Nutrient availability measured in soil samples (C/N-ratio)	-	13.2 ± 2.22	13.6 ± 1.78	n.s.
Number of plant species per plot	-	7 ± 3	8 ± 3	n.s.
vegetation height	cm	53.5 ± 13.9	46.7 ± 10.2	n.s.
water height	cm	0.0 ± 0.0	0.0 ± 0.0	n.s.
soil moisture	3 = moist 4 = moist -wet 5 = wet 6 = open water	3 = 17 4 = 12 5 = 6 6 = 7	3 = 21 4 = 16 5 = 9 6 = 5	n.s.
Thickness of the litter layer	cm	9.6 ± 10.4	8.8 ± 9.2	n.s.
Cover of open water	%	0.0 ± 0.0	0.5 ± 0.7	n.s.
Cover of litter layer	%	23.3 ± 21.7	13.3 ± 12.8	n.s.
Cover of lower herb layer	%	8.0 ± 10.8	8.0 ± 10.4	n.s.
Cover of upper herb layer	%	60.0 ± 19.8	63.3 ± 19.8	n.s.

Median ± MAD (median absolute deviation) are given in case of continuous variables. In the case of soil moisture the counts for each class are given. Results of Mann-Whitney U-test for univariate differences of parameters in occupied and vacant sites: n.s. p>0.05. Data are from Tanneberger et al. 2010 and own data.

Correlation of predictor variables

For vegetation height and the cover of the upper herb layer for the complete dataset and for soil moisture and water height for the reduced dataset (data collected in late May/early June), Spearman rank correlation coefficients were ≥ 0.7 (see Annex 14). Thus these predictor variables were not combined within one candidate model.

Model results

Results of analysis of data collected in late May/ early June

The univariate model run with water height as predictor variable was the best approximating model according to AIC-values explaining the occurrence of Aquatic Warblers in the beginning of the breeding season in Lithuania in 2011 (Tab. 4). The intercept-only model, not containing any environmental variable as main effect, was ranked in second position with a ΔAIC-value of 1.4, as well as the multivariate model considering the predictor variables vegetation height, height of litter layer, the lower herb cover, the upper herb cover and water height (Tab. 4). The univariate model testing vegetation height as predictor for the occurrence of Aquatic Warblers additionally belonged to the set of best candidate models (Tab. 4). Of the parameters belonging to these set models only the cover of the lower herb layer was significant in explaining Aquatic Warbler occurrence (Tab. 5). Water height was the most influential environmental variable according to cumulative ωAIC (Tab. 6) and model results indicate a negative correlation. Nevertheless the influence of water height in Aquatic Warbler habitat selection was not significant (Tab. 5). Nor was any of the other parameters tested (Tab. 5). Additionally the high rank of the intercept-only model (not containing any fixed effects) supports the conclusion, that no environmental variable was of high explanatory power in explaining the occurrence of Aquatic Warblers in the beginning of the breeding season in the Nemunas delta in 2006 and 2011 (Tab. 4).

Tab. 4. Model selection results of Generalized Linear Mixed Models (GLMM) for the reduced dataset with data from late May/ early June explaining occurrence of Aquatic Warblers in Lithuania in 2006 and 2011. Additive relationships among parameters indicated by "+", interaction of parameters by ":". Number of estimable parameters (k), Akaike's Information Criterion (AIC), the difference in AIC (ΔAIC) from best approximating model, Akaike weights (ωAIC) and deviance.

model	variables	k	AIC	ΔAIC	ωAIC	Deviance
1	water height	5	119,2	0	0.38	109.2
2	Intercept	4	120.6	1.4	0.19	112.6
3	vegetation height + litter height + lower herb cover + upper herb cover + water height	9	120.6	1.4	0.19	102.6
4	vegetation height	5	121.1	1.9	0.15	111.1
5	lower herb cover	5	121.5	2.3	0.12	111.5
6	vegetation height + litter height + lower herb cover + upper herb cover	8	121.7	2.5	0.11	105.7
7	soil moisture	5	122.1	2.9	0.09	112.1
8	litter height	5	122.2	3.0	0.09	112.2
9	species number	5	122.3	3.1	0.08	112.3
10	upper herb cover	5	122.5	3.3	0.07	112.5
11	vegetation height + litter height + lower herb cover + upper herb cover + soil moisture	9	123.1	3.9	0.05	105.1
12	cover litter + cover lower herb layer + cover upper herb layer + cover open soil + cover open water	9	123.9	4.7	0.04	105.9
13	vegetation height + litter height + species number + cover upper herb layer + soil moisture	9	126.5	4.9	0.01	108.5

Tab. 5. Detailed outcomes for the set of best candidate models according to AIC-values for the reduced dataset with data from late May/ early June collected in Lithuania in 2006 and 2011.

model	variables	Estimate	Std. Error	nr. of observations	p-value
1	Intercept	-0.78	0.78		0.316
	water height	-0.15	0.1	93	0.118
2	Intercept	-0.87	0.73	93	0.235
3	Intercept	2.88	2.03		0.1561
	vegetation height	-0.04	0.03	93	0.1252
	litter height	-0.04	0.04		0.3024
	lower herb cover	-0.65	0.31		0.0328
	upper herb cover	-0.06	0.19		0.7690
	water height	-0.19	0.13		0.1545
4	Intercept	0.27	1.19		0.818
	vegetation height	-0.02	0.02	93	0.210

Tab. 6. Cumulative Akaike weights (ωAIC) of predictor variables for reduced dataset with data from late May/early June collected in Lithuania in 2006 and 2011.

predictor variable	sum of ωAIC
water height	0.57
vegetation height	0.51
lower herb cover	0.51
upper herb cover	0.47
litter height	0.36

Results of analysis of the complete dataset

For the analysis of environmental variables explaining Aquatic Warblers habitat selection over the whole breeding season the model testing water height as predictor variable was ranked in first position according to AIC-values (Tab. 7). Again this parameters influence on the occurrence of Aquatic Warblers was not significant (Tab. 8). The high rank of the intercept-only model additionally illustrates that no parameter could be identified as influencing the occurrence of Aquatic Warblers in Lithuania in 2011 across the whole breeding season (Tab. 7 & Tab. 8).

Tab. 7. Model selection results of Generalized Linear Mixed Models (GLMM) for the complete dataset explaining occurrence of Aquatic Warblers in Lithuania in 2006 and 2011. Additive relationships among parameters indicated by "+", interaction of parameters by ":". Number of estimable parameters (k), Akaike's Information Criterion (AIC), the difference in AIC (ΔAIC) from best approximating model, Akaike weights (ωAIC) and deviance.

model	variables	k	AIC	ΔAIC	ωAIC	Deviance
1	water height	5	158.2	0	0.33	148,2
2	Intercept	4	159.8	1.6	0.15	151,8
3	litter height	5	160.7	2,5	0,09	150,7
4	lower herb cover	5	161.4	3.2	0.07	151,4
5	vegetation height	5	161.5	3.3	0,06	151,5
6	soil moisture	5	161.5	3.3	0.06	151,5
7	day + water height + day:water height	7	161.5	3.3	0.06	147,5
8	upper herb cover	5	161.5	3.3	0.06	151,5
9	species number	5	161.6	3.4	0.06	151,6
10	day + vegetation height + day:vegetation height	7	164.3	6.1	0.02	150,3
11	day + vegetation height + litter height + lower herb cover + day:vegetation height	9	165.0	6.8	0.01	147.0
12	day + vegetation height + litter height + lower herb cover + soil moisture + water height + day:vegetation height	11	165.3	7.1	0.01	143.3
13	day + upper herb cover + litter height + lower herb cover + soil moisture + water height + day:upper herb cover	11	165.8	7.6	0.01	143.8
14	day + upper herb cover + litter height + species number + soil moisture + water height + day:upper herb cover	11	166.9	8.7	0.00	144.9
15	day + vegetation height + litter height + species number + soil moisture + water height + day:vegetation height	11	167.2	9.0	0.00	145.2
16	day + cover litter + lower herb cover + upper herb cover + cover open soil + cover open water + day:cover of upper herb layer	11	168.2	10.0	0.00	146.2

Tab. 8. Detailed outcomes for the set of best candidate models according to AIC-values for the complete dataset collected in Lithuania in 2006 and 2011.

model	variable	Estimate	Std. Error	nr. of observations	p-value
	Intercept	-0.57	1.08		0.602
1	water height	-0,14	0,1	127	0.122
2	Intercept	-0,65	1,01	127	0.519

4.1.2 Abiotic parameters

The C/N ratios (median values per site) analysed in 66 soil samples taken in 2006 (47 samples) and 2011 (19 samples) differed significantly between study areas (Tab. 9). Nevertheless all C/N ratios were within the eutrophic trophic class, with most of the sites belonging to the eutrophic-moderately rich trophic class and Rusne being the only site in the eutrophic-rich trophic class. C/N ratios range from min. 11 (Rusne) to max. 18.22 (Tyrai mire) (based on Succow and Joosten 2001) (Fig. 5, Tab. 9 & Tab. 10).

The OM content determined in 19 soil samples collected in 2011 in Sysa, Sausgalviai and Tyrai mire as loss on ignition differed significantly between the studied areas (Tab. 9). Nevertheless, for each study area the median of OM content was > 30% (Tab. 10), with Sysa being the area with the lowest (median ± MAD 52.21 ± 15.94) and Tyrai mire the area with largest OM content (median ± MAD 74.55 ± 11.19) (Fig. 6, Tab. 9).

Tab. 9. Differences in C/N ratios and organic matter content for different studied areas in Lithuania 2006 and 2011.

study area	Sysa	Sausgalviai	Rusne	Minija	Sakuciai	Svencele	Tyrai	Test statistic	p-value
n	27	22	8	2	2	2	3		
C/N-ratio	13.8 ± 1.63	13.3 ± 1.78	11.85 ± 1.11	15.1 ± 4.30	13.1 ± 1.04	15.3 ± 2.52	16.5 ± 2.52	χ^2 = 13.6741	*
n	10	6	-	-	-	-	3		
OM content (%)	52.21 ± 15.94	73.08 ± 4.37	-	-	-	-	74.55 ± 11.19	χ^2 = 6.5189	*

Median ± MAD (median absolute deviation) are given. * Significant differences at $p < 0.05$, Kruskal-Wallis-Test with Holm correction.

Tab. 10. Trophic classes following Succow and Joosten 2001.

trophic class	oligotrophic		mesotrophic		eutrophic		polytrophic	
	very poor	poor	relatively poor	medium	moderate rich	rich	very rich	extremely rich
C/N-ratio	> 40	33-40	26-33	20-26	13-20	10-13	07-10	< 07

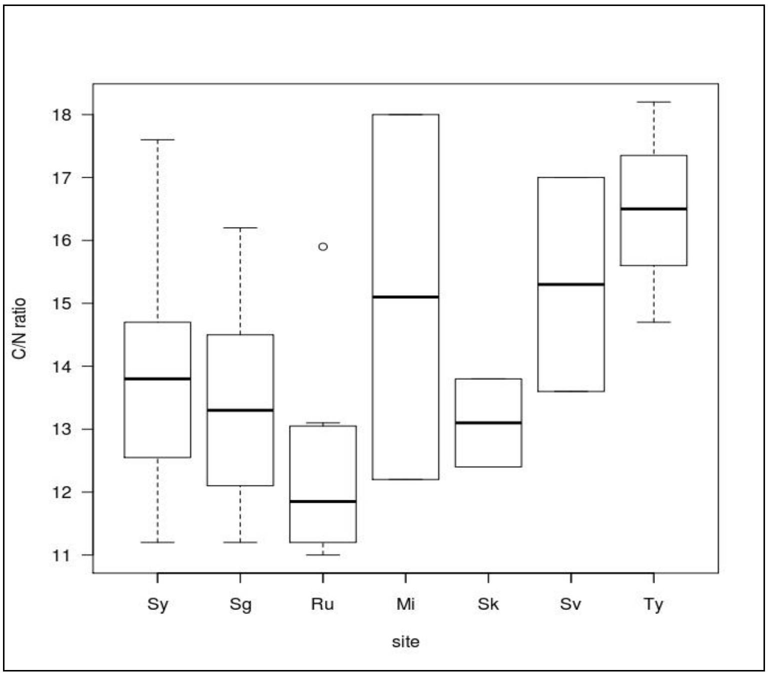

Fig. 5. Boxplots of C/N ratios of studied areas in Lithuania in 2006 and 2011.
Explanation of boxplots: the horizontal line in boxes show the median, the bottom and top of the box show the 25th and 75th percentiles (i.e. the first and third quartiles). Horizontal lines indicate the spread of the data. The point is an outlier.

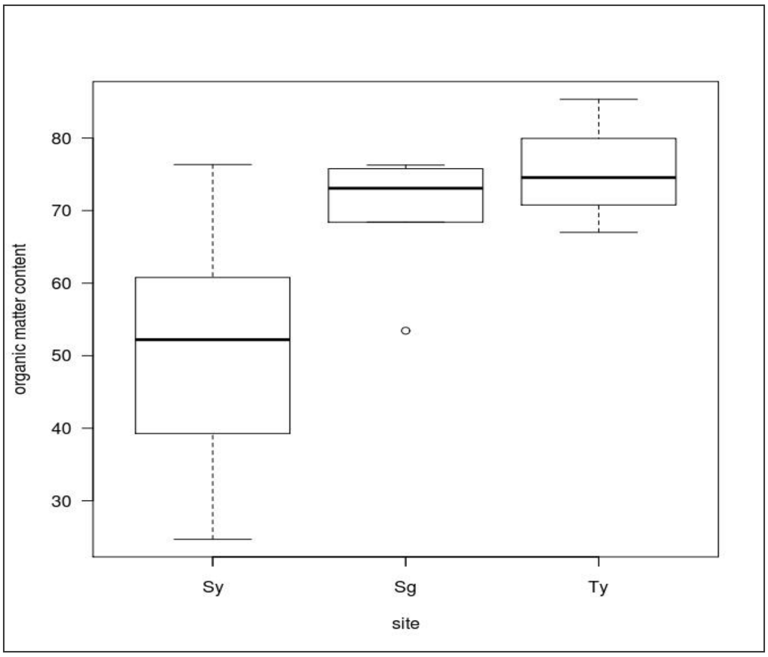

Fig. 6. Boxplots of OM content of studied areas in Lithuania in 2011.
Explanation of boxplots: the horizontal line in boxes show the median, the bottom and top of the box show the 25th and 75th percentiles (i.e. the first and third quartiles). Horizontal lines indicate the spread of the data. The point is an outlier.

4.2 General breeding biology and breeding success

4.2.1 General breeding biology

15 Aquatic Warbler nests were found in 2011 in Lithuania, 6 in Sysa, 2 in Sausgalviai and 7 in Tyrai mire. Most of the nests found were in nestling stage (10 nests).
Nest density in Sysa was 0.23 nest per 10 ha and in Sausgalviai 0.28 nests per 10 ha. For Tyrai mire nest density was not estimated, since clear boundaries of the study area have not been established.
Aquatic Warbler nests in the Nemunas delta were located on patches where *Carex gracilis* or *Phalaris arundinacea* were the dominant plant species. In Tyrai mire, where open areas dominated by *Carex disticha* alternate with reed belts of *Phragmites australis,* nests were only found in the open areas. Only one nest in Tyrai was found in vegetation dominated by *Phalaris arundinacea* and *Cirsium arvense*. Other plant species relatively frequently recorded at nest sites were *Glyceria maxima* and *Potentilla palustre* (the latter only in Tyrai mire). Nest sites did not differ visually from the surrounding area.
Nests were well hidden in stands of green vegetation with a mean height of 90.9 ± 27.8 cm (early nests, n = 7, mean ± SD) and built between stalks of sedges or reed canary grass. Nests were mostly built close to the ground in accumulations of last years vegetation. Litter height at the nest and in the nest surrounding was 14.2 ± 6.2 cm (early nests, n = 7, mean ± SD) (Tab. 11). The average height of the upper nest edge was 12.4 ± 9.3 cm (early nests, n = 5, mean ± SD) (Tab. 11), with only one nest having an upper edge as high as 29 cm. This nest was the only nest which was built rather high in a tussock of sedges on a meadow that was partly flooded in the beginning of the breeding season. Soil moisture at nest sites was moist to wet with the above mentioned nest being the only one where the soil was found to be wet. Stagnant water above ground level was completely absent in the nest vicinity at the time nests were found (Tab. 11).
Nests were covered by roofs of old vegetation to a variable extent or were only hidden by fresh green vegetation. The cover of the upper herb layer on a 1x1m^2-plot right at the nest was 88.3 ± 4.1% (early nests, n = 6, mean ± SD) and the cover of dead last years vegetation was 96.7 ± 5.7% (early nests, n = 3, mean ± SD) (Tab. 11).

Tab. 11. Nest site parameters of Aquatic Warbler nests (early brood) found in Lithuania in 2011 (n = 7).

Parameter	n	min.	max.	mean	SD
nest height (cm)	5	7.5	29	12.4	9.3
vegetation height (cm)	7	59.8	142.3	90.9	27.8
litter height (cm)	7	7.8	26	14.2	6.2
soil moisture	7	3	5	3.5	0.8
water height (cm)	7	0.0	0.0	0.0	0.0
cover of lower herb layer (%)	6	1.0	30.0	11.5	11.3
cover of upper herb layer (%)	6	80.0	90.0	88.3	4.1
cover of litter layer (%)	3	90.0	100	96.7	5.7
species number (%)	7	3	11	5.3	2.6

The calculated first laying day was May 21st and the last was July 7th, with two peaks of nest initiation (Fig. 7) (further referred to as early and late nests). The median of initiation of early nests was May 25th ± 2.97 days (n = 7) and the median of initiation of late nests was June 30th ± 2.96 days (n = 7). The average interval between early and late nests was 36 days. Nestlings of early nests mostly fledged between June 18th and June 22th (Fig. 7) (85.71% of early nests, median = June 22nd ± 2.97 days, n = 7). For another early nest (depredated) the calculated fledging date was July 3rd. The observed or calculated fledging dates for the largest proportion of nestlings of late nests were between July 23rd and August 1st (85.71% of late nests, median = July 28th ± 2.97 days, n = 7). The last observed date of fledging of an active nest was August 3rd (Fig. 7). One late nest found in the egg stage was mown on the day it was found. Hence no information about nest initiation and fledging dates are available and the nest was not considered in the calculations. The breeding period from the beginning of incubation until the last fledglings had left the nest was 76 days.

Out of 15 nests 4 suffered complete loss (26.67%). Three of the nests failed were located in Sysa, of which one nest was depredated in the beginning of the breeding season and two nests were mown late in the season (July 13th and July 18th) (Tab. 12) (see Annex 20). Another nest was depredated in Tyrai mire. Both depredated nests contained nestlings and predators could not be determined. None of the nests found was abandoned or flooded.

Thus ´traditional nest success` (*n* successful nests/ *n* total nests) would be 73%.

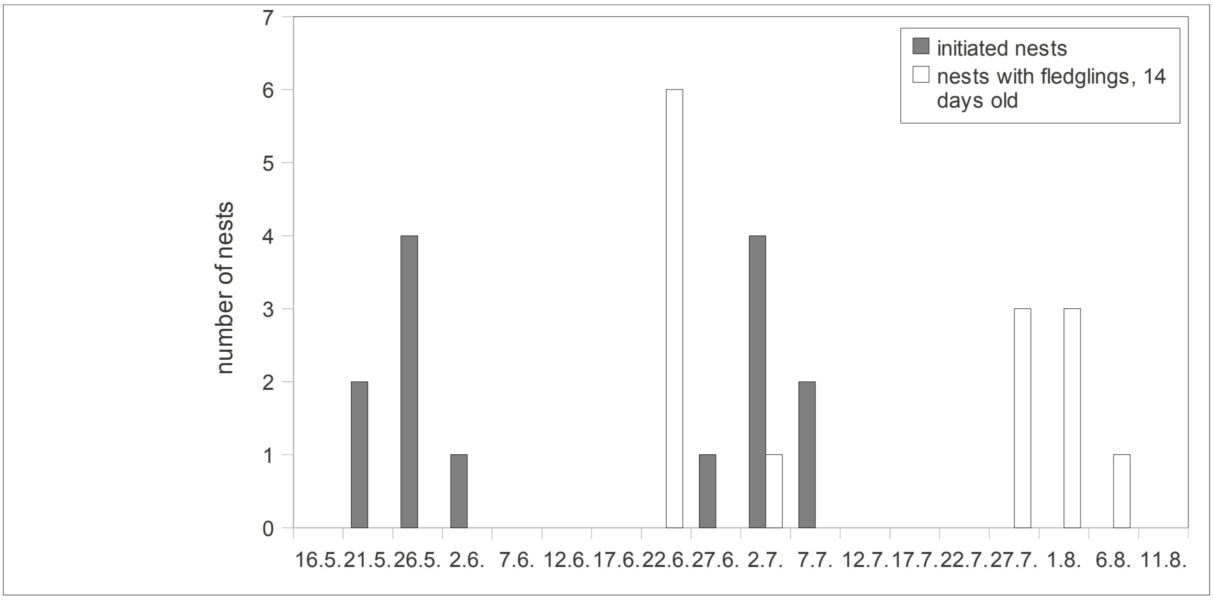

Fig. 7. Distribution of dates of nest-initiation and fledging-dates for Aquatic Warbler nests found in Lithuania during the breeding season in 2011 (n=14). All nests with observed or calculated lay- and fledging- dates were included in the sample. Division of months into five-day-intervals (pentades). Dates given are last days of pentades.

Clutch size ranged from 4 to 6 eggs (mean 5.21 ± 0.58, n = 15). Nests with 6 eggs exclusively occurred early during the breeding season and nests with four eggs were only found among late nests, resulting in a significantly higher clutch size for the early nests (mean 5.57 ± 0.53, n = 7) than for the late nests (mean 4.75 ± 0.46, n = 8; t-test p = 0.0144) (Tab. 12).

Out of 77 eggs laid 67 nestlings hatched (87%). In the successful nests some eggs did not hatch (3 eggs in the early nests and 3 eggs in the late nests, 8% of all eggs) (Tab. 12). The remaining eggs were lost due to predation either in egg-stage or in early nestling stage (5% of all eggs).

47 nestlings successfully left the nest (70% of hatched eggs). Thus 61% of all eggs laid produced fledglings. The average number of nestlings per successful nests (11 nests) was 4.3 nestlings. The averaged number of nestlings was 4.8 nestlings per successful early nest (6 nests) and 3.8 nestlings per successful late nest (5 nests).

Tab. 12. Breeding statistics of the Lithuanian Aquatic Warbler population in 2011. If not indicated elsewise, numbers given are calculated for all found nests (n = 15).

clutch size early nest (mean ± SD)	5.6 ± 0.5
clutch size late nests (mean ± SD)	4.8 ± 0.5
clutch size total (mean ± SD)	5.2 ± 0.6
unhatched eggs	8%
losses during nestling-stage	22% (13 nestlings)
% of eggs producing nestling	62% (47 eggs)
´traditional nest success` (*n* successful nests/ *n* total nests)	73% (11 nests)
nest losses due to predation	13% (2 nests)
nest losses due to mowing	13% (2 nests)
average number of fledglings per successful early nest (n = 6, mean ± SD)	4.8 ± 0.8 nestlings
average number of fledglings per successful late nest (n = 5, mean ± SD)	3.6 ± 1.1 nestlings
average number of fledglings per successful nest, total (n = 11, mean ± SD)	4.3 ± 0.9 nestlings
average number of fledglings per initiated nest, early brood (n = 7, mean ± SD)	4.1 ± 2.0 nestlings
average number of fledglings per initiated nest, late brood (n = 8, mean ± SD)	2.3 ± 1.1 nestlings
average number of fledglings per initiated nest, total (n = 15, mean ± SD)	3.1 ± 1.6 nestlings

4.2.2 Breeding success

The first model estimating survival rates for the entire sample of Aquatic Warbler nests found in 2011 was the better approximating model according to AICc-values (Tab. 13). The difference in AICc-values (ΔAICc) between the first model and the second model, evaluating separate survival probabilities for each of both study areas, was low (< 2). Thus both models received similar support by the data according to ΔAICc-values (Burnham and Anderson 2002) (Tab. 13). Nevertheless the Akaike weight (ωAICc) of the model estimating survival rates for the entire sample of Aquatic Warbler nests indicates that this model was better supported by the data.

95%-confidence intervals are rather large and indicate that the sample size is too small (n = 15 for all data) for obtaining reliable results, especially for the second model analysing separate survival probabilities for both study regions (Tab. 14).

Nest survival rate estimated for the entire dataset was 37%. Breeding success was 1.59 fledglings per nest (Tab. 15). For the second model estimating nest survival for the Nemunas delta, where most nest losses were recorded, 25% of nests survived with a breeding success of 1.05 fledglings per nest. In Tyrai mire one nest was lost due to predation. Estimated nest survival for this study area was 59% and breeding success was 2.53 nestlings per nest (Tab. 15).

Tab. 13. Model selection results of Aquatic Warbler nest survival analysis in Lithuania, 2011. Number of estimable parameters (k), Akaike's Information Criterion (AIC), the difference in AICc (ΔAICc) from best approximating model, Akaike weights (ωAIC) and deviance.

model	AICc	∆AICc	ωAICc	k	Deviance
1	29,99	0.0	0,65	1	27.96
2	31,23	1,24	0,35	2	27,12

Tab. 14. Model results of nest survival analysis of Aquatic Warbler breeding success in Lithuania, 2011. Daily survival rate (*p*) with standard error and 95% Confidence Interval are given.

model	area	*p*	95% Confidence Interval
1	Nd & Ty	0.97 ± 0.02	0.91 - 0.99
2	Nd	0.95 ± 0.03	0.86 - 0.98
	Ty	0.98 ± 0.02	0.88 - 1.0

Nd = Nemunas delta, Ty = Tyrai mire.

Tab. 15. Nest survival and breeding success of Aquatic Warblers (15 nests) in the Nemunas delta and Tyrai mire in 2011.

model	area	nest survival rate	averaged nr. of fledglings/ successful nest	breeding success
1	Nd & Ty	0,37	4.27	1,59
2	Nd	0,25	4.27	1,05
	Ty	0,59	4.27	2,53

Nd = Nemunas delta, Ty = Tyrai mire.

4.3 Aquatic Warbler nest area and meadow harvest

Twenty Aquatic Warbler males were counted in Sysa, and 11 in Sausgalviai.

In the Nemunas delta the smallest nest-male distance was 58 m and the largest nest-male distance was 116 m (n = 8 nests). The 90% percentile and the 95% percentile were 116 m as well (Fig. 8). In the Biebrza marshes the largest proportion of nests was found at a distance of 20-40 m to the nearest singing male (Fig. 8). The smallest nest-male distance was 2 m, the largest nest-male distance was 156 m. The 90% percentile was 74 m and the 95% percentile was 93 m.

Of 8 nests found in the Nemunas delta in 2011 three nests (38%) would have been protected applying the Biebrza-90% percentile in order to establish buffers around each singing male. Applying the Biebrza-95% percentile six of the nests (75%) found in the Nemunas delta would have been protected. Therefore only the use of the largest nest-male distance recorded in the Nemunas delta ensures the protection of the majority of Aquatic Warbler nests (n = 8 nests).

The Mann-Whitney U-test resulted in a significant difference of nest-male distances between both study regions (Nemunas delta: median 85.65 ± 27.12 m, Biebrza marshes: median 36.89 ± 24.05 m, $p < 0.001$).

In Sysa the nest area was 71 ha (1st count), 89 ha (adding 2nd count) and 120 ha (adding 3rd count) (Fig. 9). The designation of parts of meadows to be spared from mowing based on a single count in June therefore would have protected approximately 60% of Aquatic Warbler nest area. In Sausgalviai nests were expected within 29 ha (1st count), 39 ha (adding 2nd count) and 42 ha (adding 3rd count) (Fig. 9). Therefore 69% of nest area would have been protected by sparing area from mowing based on a single count in June.

In Sysa 8% of the nest area derived by the first count in June extended into neighbouring parcels and would have been lost, if only parts of meadows with records of singing males were spared from mowing. For the complete nest area derived from the three counts this areas proportion was 14%. In Sausgalviai nest area was only recorded on meadows with meadows with Aquatic Warbler records.

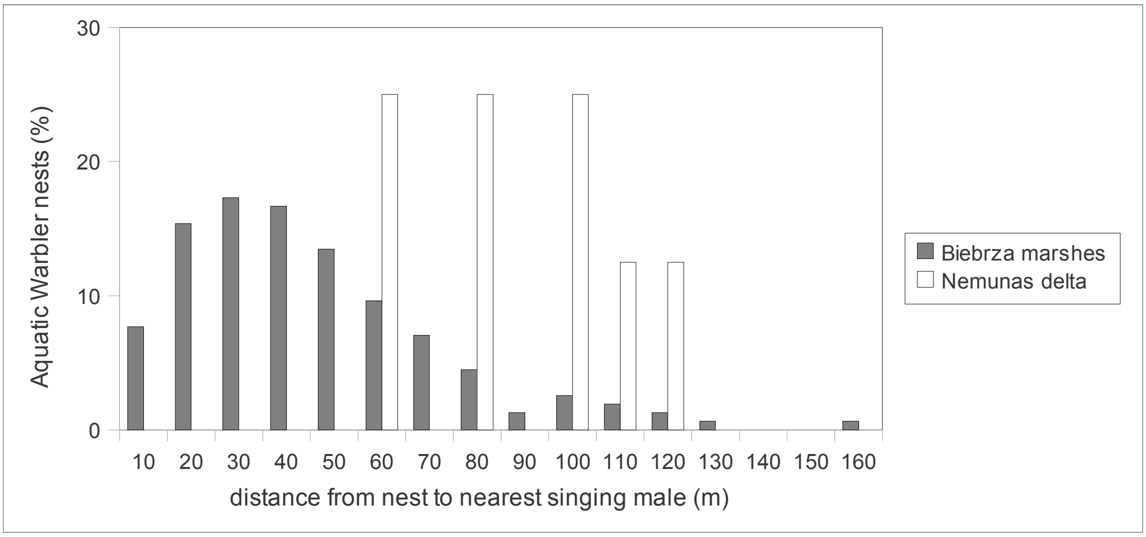

Fig. 8. Frequency distribution of distances between Aquatic Warbler nests and the nearest male singing in the Biebrza marshes, Poland (n = 156 nests) and the Nemunas delta, Lithuania (n = 8 nests). Data from the Biebrza marshes are from OTOP, data from the Nemunas delta are own data. All data are from 2011.

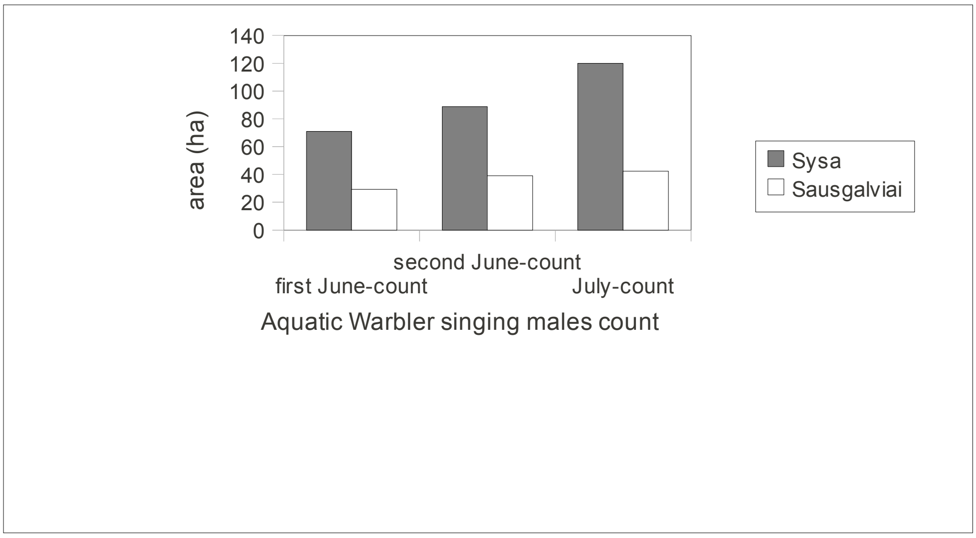

Fig. 9. Cumulative Aquatic Warbler nest area (ha) in Sysa and Sausgalviai in 2011. Nest area was calculated based on the recorded Aquatic Warbler singing males per indicated count. See text for explanation of calculation. Each bar illustrates the cumulative sum of nest area, including nest area derived from previous counts (July-count = 100% nest area).

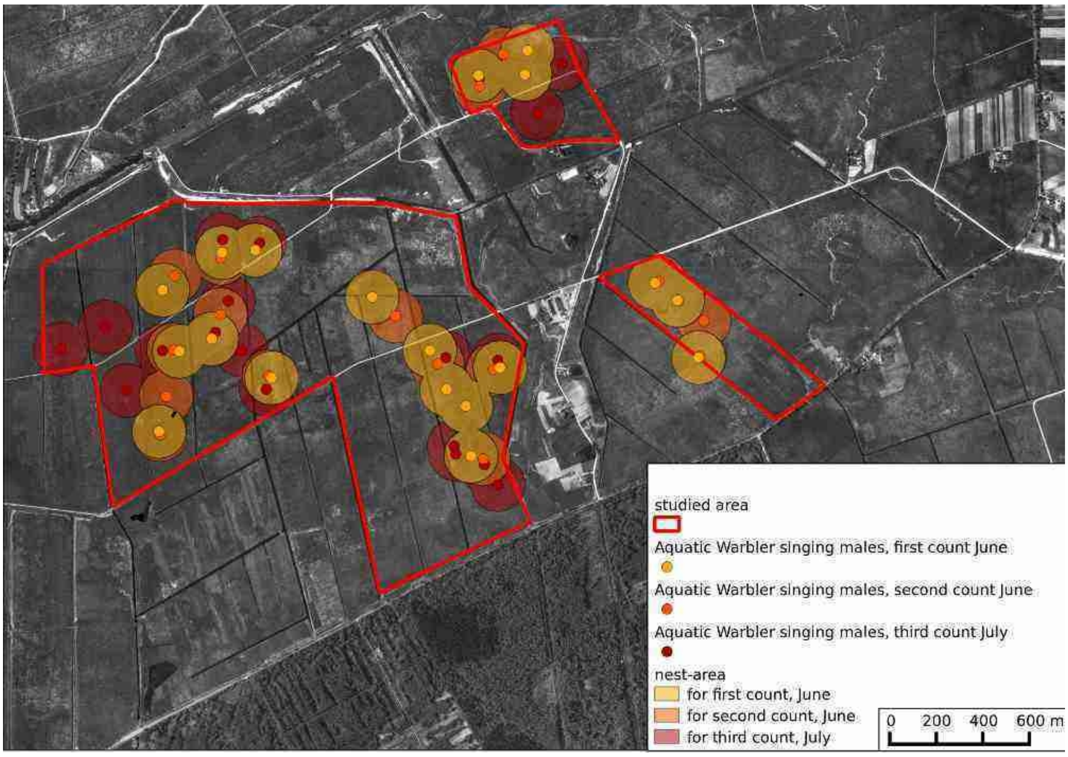

Fig. 10. Distribution of Aquatic Warbler singing males and nest area in Sysa, 2011. nest area was derived from three consecutive counts of singing males. See text for further explanation.

Fig. 11. Distribution of Aquatic Warbler singing males and nest area in Sausgalviai, 2011. nest area was derived from three consecutive counts of singing males. See text for further explanation.

In Sysa 74.45% of nests-area was lost due to mowing (Fig. 12 & Fig. 13). The largest proportion of nest area was mown during the second half of July (31.22%), when late nests are in the nestling stage (Fig. 7). In Sausgalviai losses were in total 39.43% of the nest area, with the largest proportion of losses in June (32.61%), when nests of the early brood are still active (Fig. 12 & 14).

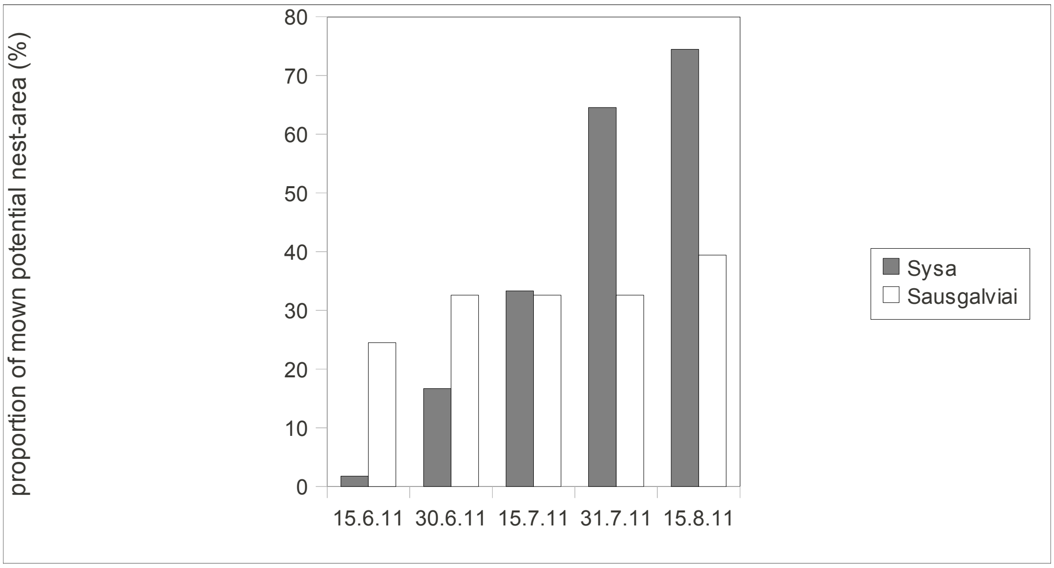

Fig. 12. Mown Aquatic Warbler nest area (ha) in Sysa and Sausgalviai in 2011. Dates indicate the last day of an interval monitored. Each bar illustrates the cumulative sum of mown area, including nest area derived from previous counts (15.8.11 = 100% mown nest area).

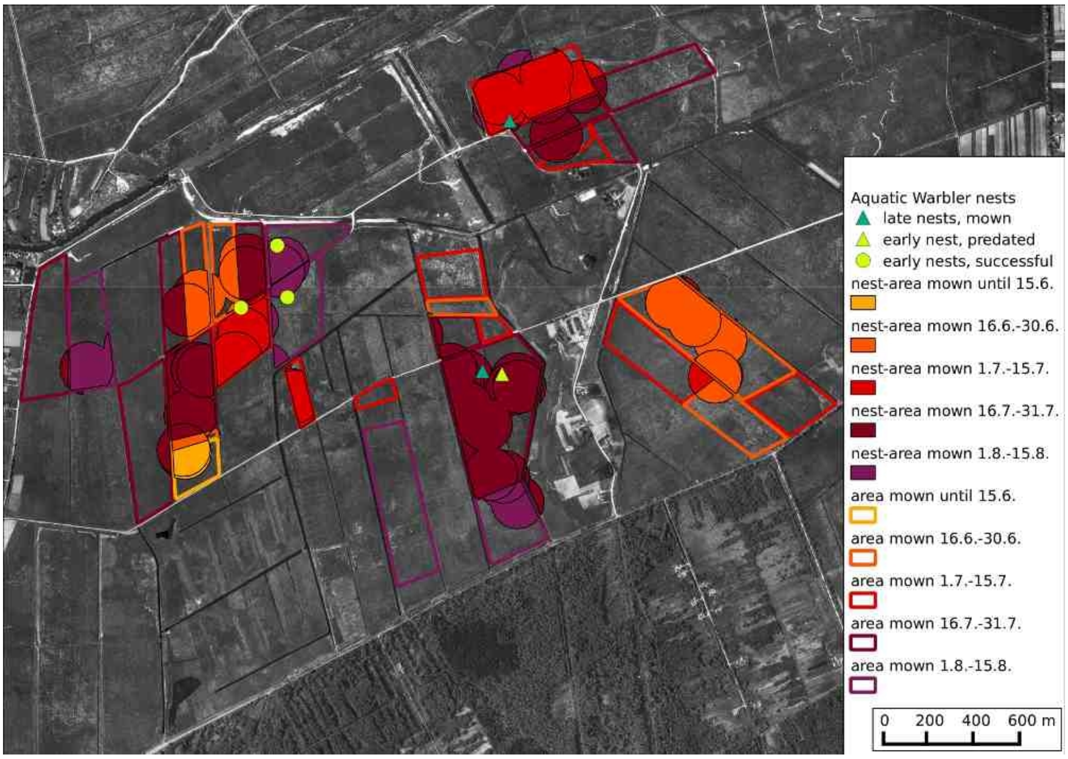

Fig. 13. Mown Aquatic Warbler nest area, Sysa 2011.

Fig. 14 Mown Aquatic Warbler nest area, Sausgalviai 2011.

5 DISCUSSION

5.1 Interpretation of model results

As a habitat specialist the Aquatic Warbler relies on a set of highly specific habitat parameters (Leisler 1981, Schulze-Hagen 1991). Environmental variables previously identified as being crucial in Aquatic Warbler habitat selection (i.e. vegetation structure parameters identified by Leisler 1981, Schulze-Hagen 1991, Kozulin and Flade 1999, Tanneberger et al. 2008, Tanneberger et al. 2010) could not be identified with the available data set for Lithuania. The explanatory power of tested variables seemed to be generally low. Possible explanations are discussed in the following.

In studies on Aquatic Warbler habitat selection in Pomerania (Tanneberger et al. 2008, Tanneberger et al. 2009, Tanneberger et al. 2010) study sites have been chosen, that were occupied by Aquatic Warblers at the period of data sampling. Additionally sites with historical records of Aquatic Warblers were studied. These sites were abandoned by Aquatic Warblers up to five years before study (Tanneberger et al. 2008, Tanneberger et al. 2010). For identifying the parameters influencing Aquatic Warblers habitat selection in Pomerania therefore a precise classification of study sites into sites being frequently occupied and not being occupied by Aquatic Warblers was possible.

In Lithuania, especially for the 2011 data, sites with and without Aquatic Warbler records were chosen according to the distribution of Aquatic Warblers in the year of study. Nevertheless old Aquatic Warbler records from the Nemunas delta, especially Sysa, reveal that birds to some extent were observed in preceding years on different meadows than in the year of the presented study. For the May dataset collected in 2006 only 6 out of 29 studied sites were without Aquatic Warbler records back until 2006. Information on exact distribution of Aquatic Warblers before 2006 was not available.

Factors driving Aquatic Warblers to change meadows in different years are so far unknown. Telemetry studies revealed a tendency to aggregate in Aquatic Warblers (Schaefer et al. 2000). A higher probability of occurrence in sites located in a close distance to other sites occupied was shown (Tanneberger et al. 2010). This can be explained by the mating system varying between promiscuity and polygyny (Dyrcz and Zdunek 1993a, Schulze-Hagen et al. 1999). Females seem to chose nest sites and feeding areas as a function of habitat parameters such as prey availability (Dyrcz and Zdunek 1993a). Males tend to aggregate in places where fertile females likely are to be available (Schulze-Hagen et al. 1999).

The Aquatic Warbler population in the Nemunas delta currently is declining and the population size might not be large enough for all suitable meadows to be occupied. In consequence meadows actually being suitable as Aquatic Warbler habitat might have remained vacant. They would have been treated as ´absence-sites` in data analysis even though notable differences to the sites treated as ´presence-sites` do not exist. Presumably the dataset is lacking a sufficient amount of sampled sites not suitable for the Aquatic Warbler.

It is further speculated, that certain not tested environmental variables strongly influence the distribution of Aquatic Warblers, i.e. the progress of meadow harvest might force the birds to resettle from sites suitable for breeding to less suitable sites. If a parameter not included in the dataset is the major factor determining the occurrence of Aquatic Warblers, the impact of tested parameters might not be identifiable.

With the progress of the breeding season and the progress of the meadow harvest Aquatic Warbler singing males might be forced to resettle to a meadow less suitable for breeding. In such a case the meadow would be treated as a ´presence-site`. Therefore a study on Aquatic Warbler habitat selection over the whole breeding season in the highly dynamic Nemunas delta does not seem to be reasonable.

The present study was carried out within one potential habitat type, the eutrophic sedge sites. Potentially existing differences in vegetation structure of sites with and without Aquatic Warbler presence are most likely small-scale differences. In order to identify these differences a large sample of occupied and unoccupied sites would be essential, which most likely was not the case within this study.

In conclusion an appropriate differentiation of sites into ´presence-sites` and ´absence-sites` is rather difficult. Even though previously identified parameters might be crucial in Aquatic Warbler habitat selection in Lithuania, their influence therefore was not statistically identifiable.

Whittingham et al. (2006) analysed data of a 4 years field study on Yellowhammer (*Emberiza citrinella*) territory occupancy. Single year data analysed separately were insufficient to identify a model clearly better explaining Yellowhammer territory occupancy than the other models. Even analysing the complete 4 year dataset did not result in a single model clearly outperforming the other models (Whittingham et al. 2006).

Therefore it can be assumed that habitat data collected in 2 years (2006 and 2011) within one habitat type were insufficient for identifying parameters explaining Aquatic Warbler occurrence in Lithuania. A study on Aquatic Warbler habitat selection conducted over a period of a few years is recommended. The spatial scale of the study should be extended as well, possibly including different habitat types, e.g. Tyrai mire, the area with highest Aquatic Warbler density in Lithuania. Additionally areas that used to be occupied by Aquatic Warblers, but for that no current records exist (e.g. Minija and Sakuciai), could be more comprehensively sampled.

5.2 Aquatic Warbler habitat in the Nemunas delta

5.2.1 Soil conditions

According to the results of the determination of OM content in soil samples collected in Tyrai mire, Sysa and Sausgalviai, soils of all three sites can be regarded as peatsoils. Peat is defined as sedentarily accumulated material consisting of at least 30% dry mass of dead organic material. A peatland is an area with or without vegetation with a naturally accumulated peat layer on the surface (Joosten and Clarke 2002). Still, OM content in Sysa is markedly lower than in the other study areas.

In flood mires (Joosten & Clarke 2002), which are typical for large river deltas in Europe (Timmermann et al. 2009), the peat has typically a relatively high mineral material content. In the district of former Heydekrug (nowadays Silute) peatsoils were reported to be abundant and drainage systems (i.e. ditches) used to be active already in the end of the 19th century (Fleischer 1882). Therefore, given the prevalence of shallow fen peat layers in Sysa, substantial parts of the peat may have been cut or mineralised and the mineral components became even more pronounced (F. Tanneberger, pers. comment).
In drained peatlands mineralisation of organic soils leads to increased soil nutrient availability for plants (Succow and Joosten 2001, Olde Venterink et al. 2009, Rosenthal and Hölzel 2009).

All studied Lithuanian Aquatic Warbler breeding areas belong to the eutrophic trophic class (cf. Succow and Joosten 2001). Site conditions of the studied Aquatic Warbler breeding areas in Lithuania belong to the the most eutrophic Aquatic Warbler breeding sites (Tab. 16). So far only a few Aquatic Warbler populations breed in habitats with eutrophic site conditions (Kozulin & Flade 1999, Tanneberger et al. 2008, Tanneberger et al. 2010). The major Aquatic

Warbler breeding areas with mesotrophic site conditions are the areas that hold 97% of the total world population and are regarded as typical Aquatic Warbler habitats (AWCT 1999, Kozulin and Flade 1999). Findings from Belarus showed, that Aquatic Warbler density is highest on mesotrophic sites and decreases at a higher and a lower trophic level (Kozulin and Flade 1999). Also for Pomerania the probability of occurrence is higher in the mesotrophic reed sites than in the eutrophic sedge sites (Tanneberger et al. 2010) (Tab. 16).

Peat mineralisation currently is an ongoing process in the Aquatic Warbler habitats in the Nemunas delta. Therefore a high nutrient availability will remain a matter of concern (Succow and Joosten 2001, Kratz and Pfadenhauer 2001, Rosenthal and Hölzel 2009, Olde Venterink et al. 2009). Site conditions with a higher nutrient availability imply a high amount of standing biomass, a dense vegetation structure and the dominance of nutrient demanding tall growing plant species (Rosenthal and Hölzel 2009). This is in complete contrast to habitat preferences of Aquatic Warblers (Tanneberger et al. 2008, Tanneberger et al. 2010). Nevertheless, in order to better verify these assumptions further research on soil conditions in the Lithuanian Aquatic Warbler breeding habitats is needed.

5.2.2 Vegetation structure

With 46.7 ± 10.2 cm (median ± MAD) vegetation height in current Aquatic Warbler sites in Lithuania in late May/ early June does not exceed the optimal vegetation height recorded in other studies on Aquatic Warbler habitat selection (Tab. 16). An optimal vegetation height of less than 70 cm in the beginning of the breeding season is reported for Aquatic Warbler breeding areas in Pomerania (Tanneberger et al. 2010). In the major breeding areas in Eastern Poland and Belarus optimal vegetation height is 60-80 cm (Dyrcz and Zdunek 1993, Kozulin and Flade 1999) (Tab. 16). In these percolation mire habitats a thick litter layer is of great importance as it is needed for building nests above water level (Dyrcz and Zdunek 1993a, Kozulin and Vergeichik 2006). Additionally the cover of the moss layer with its oscillating characteristics is important for the survival of nests when water table is fluctuating (Kozulin and Flade 1999, Kozulin and Vergeichik 2006). In Belarus the highest density of Aquatic Warblers was observed in areas with a cover of 90-100% of mosses (Kozulin and Flade 1999). Compared to the core habitats the thickness of the litter layer in Lithuania was markedly low and mosses and water above ground level were absent (Tab. 16), as it was the case in the floodplain meadows of the Lower Oder Valley and Rietzer See, Germany (Wawrzyniak and Sohns 1977, Tanneberger et al. 2008, Tanneberger et al. 2010). A low litter layer is especially important in the floodplain meadows (Tanneberger et al. 2008, see below) and should not exceed 10 cm (Tanneberger et al. 2010). In sites occupied by Aquatic Warblers in Lithuania litter layer is less than 10 cm (8.82 ± 9.22) (median ± MAD), but high compared to sites with Aquatic Warbler records in the eutrophic sedge sites in Pomerania (0.6 ± 0.8 cm) (median ± MAD) and rather resembles the unoccupied sites in this breeding region (10.5 ± 15.5 cm) (median ± MAD).

Most likely the relatively low litter layer and vegetation height in the eutrophic sites of the Nemunas delta are caused by meadow harvest. In nutrient rich site conditions annual hay-removal may prevent increase of standing crop biomass and therefore the establishment of a thick litter layer and high vegetation (Leps 1999, Billeter et al. 2007, Olde Venterink et al. 2009). The cover of the upper herb layer in the Nemunas delta (63.3 ± 19.8%) (median ± MAD) is only slightly higher than in the Pomeranian sedge and reed sites occupied by Aquatic Warblers (Tab. 16). A maximum cover of the upper herb layer of 60% of the soil covered seems to be beneficial (Tanneberger et al. 2010).

Aquatic Warblers frequently use the vegetation for climbing and foraging (Leisler 1981), which is probably hindered by a thick litter layer, a high vegetation and a dense cover of the upper herb layer (Wawrzyniak and Sohns 1977, Tanneberger et al. 2010). Additionally these factors lead to microclimatic conditions less favourable for arthropod larval development, i.e. due to retarded warming of the soil surface in spring (Buttler 1992, Kozulin and Flade 1999, Tanneberger et al. 2008, Tanneberger et al. 2010), and negatively affect the abundance of flowering plants in the lower herb layer (Lepš 1999, Pfadenhauer et al. 2001, Gerard et al. 2008). With 8% of the soil surface covered (8.0 ± 10.4%) (median ± MAD) the cover of the lower herb layer was markedly lower in Lithuania than in the Pomeranian breeding sites (Tab. 16) (Tanneberger et al. 2010). The cover of the lower herb layer most likely is related to prey supply, as it delivers feeding grounds for nectar-collecting insects (Tanneberger et al. 2010). It is suggested, that a cover of the lower herb layer of approximately 20% of the ground covered would be the optimal condition for Aquatic Warblers in the floodplain polder habitats (Tanneberger et al. 2010) (Tab. 16).

The low cover of the lower herb layer in the studied areas points out to the importance of investigating prey supply in the Lithuanian Aquatic Warbler breeding habitats.

Tab. 16. Comparison of different Aquatic Warbler habitats. Table from Tanneberger et al. 2008, data for Lithuania modified based on own results

Aquatic Warbler breeding area	Density (sm/ 10 ha)	Vegetation height (cm)	Thickness of litter layer (cm)	Cover of mosses (%)	Water level (cm)	Cover of the upper herb layer (%)	Cover of the lower herb layer (%)	Water level amplitude April-August (cm)	Nutrient availability (trophic class)
Floodplain polders									
Lithuania, Nemunas delta [a]	0.7 - 1.7	46.7 ± 10.2	8.8 ± 9.2	0 ± 0	0 ± 0	63.3 ± 19.8	8.0 ± 10.4	high (>50)	eutrophic (13.6 ± 1.78, incl. Tyrai mire)
Pomerania, sedge sites (Lower Oder valley) [b]	0.9 - 1.7	58.4 ± 8.2	0.6 ± 0.8	0	max. 0.5 cm in late May/ early June	55.0 ± 27.2	19.0 ± 4.7	high (>50)	eutrophic (15.2 ± 2.8)
Valley fen									
Pomerania, reed sites (Rozwarowo) [c]	0.71 - 1.19	69.6 ± 19.8	8.2 ± 2.7	17.9 ± 20.6	2.3 ± 3.5	53.3 ± 24.7	16.7 ± 17.8	NA	mesotrophic (22.5 ± 7.1)
Percolation mires									
Poland, Biebrza valley [d]	1 - 11	60 - 80	high (29 - 39)	40 - 100	0 - 25	NA	NA	low	mesotrophic (mean ± SD: 21.45 ± 2.2)
Belarus, fen mires [e]	1 - 13.5	60 - 70	medium to high (10 - 35)	90 - 100	0 - 30	NA	NA	low (0 - 20)	mesotrophic (mean: 20.2)

Median ± MAD are given, if not indicated otherwise. Coverages are percentage of ground covered. NA = not available.

[a] Vegetation structure data are from Tanneberger et al. 2010 and own data, collected in late May/ early June 2006 and 2011. Singing males data from BEF. Water level amplitude from Tanneberger et al. 2008.

[b] Tanneberger et al. 2010

[c] Tanneberger et al. 2010

[d] Dyrcz and Zdunek 1993a; Sellin 1989 and Wassen and Joosten 1996 (soil C/N ratio for Biebrza Upper Basin) in Tanneberger et al. 2008

[e] Kozulin and Flade 1999, Vergeichik and Kozulin 2006b; Stephanovich (litter layer) and Bambalov (soil C/N ratio) in Tanneberger et al. 2008

5.2.3 Nest sites

In the large mires of Belarus nests were arranged in accumulations of old vegetation on plant tussock tops or, if water tables were low, on the soil surface (Vergeichik and Kozulin 2006b). In the Biebrza marshes nest places differed from their surrounding by the presence of a higher amount of sedges forming a roof above the nest and a higher water level between the tussocks, with a mean water height at the nest of 3.91 ± 1.71 cm (Dyrcz and Zdunek 1993a). A high litter layer in the core population habitats is important for nest building above water level (Dyrcz and Zdunek 1993a, Vergeichik and Kozulin 2006b). In the Nemunas delta and in Tyrai mire nests were placed close to the ground (Tab. 11), as it is usual in the floodplain polder habitats (Wawrzyniak and Sohns 1977, Vergeichik and Kozulin 2006b, Tanneberger et al. 2008). Nest site conditions of early nests in Lithuania were generally similar to nest site conditions of early nests in managed meadows of the floodplain polders in Pomerania (Tab. 17).

Tab. 17. Site conditions at Aquatic Warbler nests (early brood) in Lithuania and in Pomerania.

	Lithuania (n = 7)	Pomerania (n = 3)
Vegetation height (cm)	90.9 ± 27.8	88.2 ± 9.3
Litter height (cm)	14.2 ± 6.2	9.4 ± 4.1
Water height (cm)	0	0
Soil moisture	moist to wet	moist to wet
Cover of upper herb layer (<30 cm) (%)	88.3 ± 4.1	75 ± 21
Cover of lower herb layer (>30 cm) (%)	11.5 ± 11.3	25 ± 21

Data from Pomerania are from Tanneberger 2008, data from Lithuania are own data. Mean ± SD are given.

5.2.4 Importance of water level

Water height in current Aquatic Warbler sites in the Nemunas delta was lower compared to the core population habitats (Dyrcz and Zdunek 1993a, Kozulin and Flade 1999, Vergeichik and Kozulin 2006b) (Tab. 16). The low litter layer, the absence of water above ground level on sites occupied by Aquatic Warblers and the majority of nests being placed near or right at the soil surface fit well to the model outcomes indicating a low water level positively influencing the occurrence of Aquatic Warblers. These findings indicate that Aquatic Warbler breeding habitats in Lithuania are of the same habitat type as the floodplain polder breeding habitats studied so far. A high litter layer is not important in nest site selection and flooding from May onwards, when Aquatic Warblers start nest building, would preclude nest placement close to the soil surface.

Nevertheless water is a crucial factor for maintaining a suitable habitat for the Aquatic Warbler and changes in water table have been identified as one of the major threats for Aquatic Warblers in the Nemunas delta (AWCT 1999). At Rietzer See a lack of water in spring resulted in Aquatic Warblers being only found in moist patches or near ditches, where most water was present (Wawrzyniak and Sohns 1977). A water table near the soil surface in spring is crucial to ensure the development of a vegetation structure necessary for the Aquatic Warbler. In dry vegetation nests of Aquatic Warblers are poorly hidden and thus more vulnerable to predators (Vergeichik and Kozulin 2006b, Kozulin and Vergeichik 2006). The existence of species rich wet meadows on degraded fens depends on water tables above soil level in winter and at soil level in spring. In summer time the water table should not fall below approximately 40 cm below the soil surface (Pfadenhauer et al. 2001). Additionally a lack of water in early spring eventually would result in a limited availability of prey supply. The development of insect biomass (i.e. water stages of larval development) is dependent upon the availability of open water and well developed green vegetation (Vergeichik and Kozulin 2006b, Kozulin and Vergeichik 2006). Therefore lowering of the water table in the Nemunas delta far below the soil surface should be avoided in order to maintain a habitat suitable for the Aquatic Warbler.

5.3 General breeding biology and breeding success of the Aquatic Warbler in Lithuania

5.3.1 General breeding biology

Results on breeding biology of Aquatic Warblers in Lithuania in 2011 are similar to previous findings from other breeding areas.

The breeding period in the Aquatic Warbler lasts from early May until the end of July (Schulze-Hagen 1999) or even until the last days of August (Wawrzyniak and Sohns 1977). The general timing of the breeding period in Lithuania in 2011 was typical for the species, because the first clutches started during May and the last clutches started in July (Vergeichik and Kozulin 2006b).

Aquatic Warblers in Lithuania seem to attempt to rear early and late broods. This is known from other Aquatic Warbler populations as well (Wawrzyniak and Sohns 1977, Dyrcz and Zdunek 1993a, Vergeichik and Kozulin 2006a). The average interval between early and late broods (36 days) was similar to the Biebrza marshes (41 days) (Dyrcz and Zdunek 1993a), as were the calculated first egg-laying date of early nests and the calculated first egg-laying of late nests (Tab. 18).

Nest density in the Nemunas delta was low (0.23 nests/10ha in Sysa, 0.28 nests/10ha in Sausgalviai) compared to the core breeding areas (6.6-11.6 nests/10ha in Belarus) as well as to the floodplain meadows at Rietzer See (0.53 nests/10ha) (Wawrzyniak and Sohns 1977, Kozulin and Vergeichik 2006).

A higher clutch size in early nests is well in accordance with records from all other breeding areas (Wawrzyniak and Sohns 1977, Dyrcz and Zdunek 1993b, Vergeichik and Kozulin 2006). Also in the floodplain meadows at Rietzer See and in the core population habitats in Biebrza marshes clutches of 6 eggs exclusively occurred in early nests and 4 eggs occurred in late nests (Wawrzyniak and Sohns 1977, Dyrcz and Zdunek 1993b). The median of 5 eggs per clutch resembles to the core population in Biebrza marshes as well (Dyrcz and Zdunek 1993b).

The amount of unhatched eggs was similar to the Biebrza marshes (7.8% in Lithuania, 8.6% in Biebzra marshes) and the proportion of fledglings per eggs laid was nearly the same, as was the averaged numbers of nestlings per successful and per initiated nest (Dyrcz and Zdunek 1993b).

Tab. 18. Timing of the breeding season of Aquatic Warblers in different breeding areas.

area	first laying date	last laying date
Lithuania 2011[a]	May 21st	July 7th
Biebrza marshes 1986-1991[b]	May 10th	NA
Biebrza marshes 2010[c]	May 8th	July 17th
Biebrza marshes 2011[c]	May 17th	August 8th
Belarus[d]	May 10th	July 22nd
Rietzer See, Germany[e]	May 13th	July 24th

Data are from [b]Dyrcz and Zdunek 1993a, [c]Kubacka et al. unpublished, [d]Kozulin and Vergeichik 2006, [e]Wawrzyniak and Sohns 1977 and [a]own data. NA = not available.

5.3.2 Breeding success of the Aquatic Warbler and the impact of meadow harvest

In order to properly understand factors affecting changes in bird populations realistic estimates of breeding performance are essential (Alker and Redfern 2010). Due to the small number of Aquatic Warbler nests the reliability of the presented results of breeding success and nest survival should be treated with caution. Available results are only very rough estimates and conclusions can only be drawn based on the assumption that an analysis with a larger sample size would have delivered similar outcomes. Finding many Aquatic Warbler nests is virtually impossible in such a small population with a low density of individual birds, as it is the case for the Aquatic Warbler in Lithuania. Thus, even this analysis based on a very small sample size (n = 15 nests) provides valuable information on the condition of the Lithuanian Aquatic Warbler population, that should be taken into consideration whilst developing conservation measures.

Due to the small sample size the combined analysis of breeding success and nest survival for the study regions Nemunas delta and Tyrai mire was essential. But since both study areas are subject to different forms of land use, this analysis does not seem to be plausible. In the Nemunas delta meadows are privately owned and mown for hay making from the beginning of the breeding season onwards. Tyrai mire is state owned and land use takes place only in the framework of conservation activities. Thus, since the model analysing nest survival and breeding success separately for both study areas was not rejected completely according to the ∆AIC-value, also this models result will be considered in the following.

For the latter analysis nest survival rate in the Nemunas delta (25%) was markedly lower than in Tyrai mire (59%). Nest losses due to mowing only occurred in the Nemunas delta (13.3% of all nests), giving rise to the conclusion that mowing negatively affected Aquatic Warblers breeding performance.

For the Nemunas delta no information on Aquatic Warblers breeding success without any influence of meadow harvest exist. In Tyrai mire only few habitat data were collected. Nevertheless the comparatively high breeding success in Tyrai mire might reveal a better habitat quality there.

Nest survival in Lithuania was slightly lower than in the Biebrza marshes in Poland (37% in Lithuania vs. 41% in the Biebrza marshes in 2010 and in 2011) (unpublished data from OTOP). For the separate areas nest survival in the Nemunas delta was considerably lower (25% vs. 41% successful nests). In Tyrai mire nest survival was higher (59% vs. 41%

successful nests), whereas this finding does not seem to be plausible and most likely results from the small sample size (see below). The Biebrza marshes host one of the largest stable core populations of the Aquatic Warbler (Flade and Lachmann 2008) and habitat conditions are regarded as typical Aquatic Warbler habitats (AWCT 1999). Agricultural use is absent and land management only takes place in the framework of conservation activities.
Breeding success in Lithuania was with 1.59 fledglings per nest only slightly lower than in the Biebrza marshes in 2010 (1.74 fledglings per nest).

In the Nemunas delta in 2011 Aquatic Warblers bred in meadows that were mown to a large proportion in June and July. Most likely Aquatic Warbler nests were not distributed evenly within the estimated nest area, indicated by the few nests found in comparison to the amount of singing males present. Therefore the estimated proportion of mown nest area does not equal the actual loss rate of nests. Nevertheless this areas large proportion mown as well as the very low breeding success of Aquatic Warblers in the Nemuna delta highlights the negative impact of meadow harvest on the Lithuanian Aquatic Warbler population. In Sysa mainly the late brood was affected, indicated by the actual loss of nests due to mowing. In Sausgalviai already in June a large proportion of nest area was mown, possibly damaging nests of the early brood.
In a study on Whinchat breeding success (Broyer 2009) the density of passerine territories increased with the progress of meadow harvest. This was paralleled by competition for food resources and negatively correlated with breeding success (Broyer 2009). Foraging areas of Aquatic Warbler females nesting close together do not overlap (Dyrcz and Zdunek 1993a), while aggressive interactions among foraging females are frequent (Schulze-Hagen 1991). A decrease in suitable breeding area only provides habitat for a limited amount of nests and will affect the populations reproductive performance.

Thus, meadow harvest can be regarded as a serious threat to the Lithuanian Aquatic Warbler population and mowing dates should be better adjusted to the timing and distribution of Aquatic Warbler broods.

5.4 Management recommendations

5.4.1 Earliest mowing date for parts of meadows occupied by Aquatic Warblers

Aquatic Warblers in the Nemunas delta (Sysa and Sausgalviai) seem to initiate late/ second broods. Due to the progress of mowing these late broods could not be completed successfully.

Therefore the estimated 1.59 fledglings per nest have to be treated as the reproductive output per female resulting from a single brood. For other trans-Sahara migrants, i.e. the Whinchat, it was reported that 1.5 nestlings have to successfully fledge the nest per adult bird (which is 3 nestlings per nest per breeding pair) within one breeding season in order to maintain a stable population size (Bastian and Bastian 1996). It was assumed that this number applies for the Aquatic Warbler as well (Helmecke et al. 2003). Several authors observed more Aquatic Warbler males than females within one breeding area (Wawrzyniak and Sohns 1977, Dyrcz and Zdunek 1993a, Giessing 2002). In such a case even more than 3 fledglings per nest would be necessary to maintain population size, if females only rear one brood (Helmecke et al. 2003). Consequently the breeding success of Aquatic Warblers in Lithuania only is sufficient to maintain the population size, if every female bird is able to inititate two broods. This finding does not differ from other studies (Helmecke et al. 2003). Even though the protection of nests of the early brood is especially important since clutch size is higher, females must be able to rear late broods. The survival of each individual nest is especially important, if only few nests are present. Aquatic Warbler nestlings are not able to fly after leaving the nest for another 5-8 days (Wawrzyniak and Sohns 1977, Schulze-Hagen 1995). This should also be considered whilst establishing earliest mowing dates. In Lithuania in 2011 by August 1st 25% of nests were still active. All nestlings fledged by August 15th. An earliest mowing date at August 15th therefore is recommended in order to protect every initiated Aquatic Warbler nest over the whole breeding season.

Several bird species rely on managed grassland. An earliest first mowing date before the end of June might would result in detrimental effects for several bird species, such as Yellow Wagtails, Whinchats and Corncrakes (Heer et al. 2000, Bellebaum et al. 2002, Broyer 2009, Fischer et al. 2012). In the Nemunas delta Corncrakes, listed in European Birds Directive Annex I, breed in the same meadows as the Aquatic Warbler and would also greatly benefit from a delayed earliest mowing date at August 15th (Heer et al. 2000).

5.4.2 Designation of areas to be spared from mowing

In order to protect every initiated Aquatic Warbler nest over the whole breeding season, the parts of the meadows where Aquatic Warblers are recorded should be spared from mowing. The search for every single nest is not feasible and can not be recommended for such an endangered bird species. Therefore it is proposed to protect Aquatic Warbler nests via the location of singing males.

In the Biebrza marshes the nest-male distances were markedly lower than in the Nemunas delta. This most likely is attributed to the high density of Aquatic Warblers in the Biebrza marshes (0.4 singing males/ 10 ha in Sysa and 1.5 singing males/ 10 ha in Sausgalviai in 2011 (data from BEF and own data) vs. 161.9 - 163.3 singing males/ 10 ha in the Biebrza marshes (Flade and Lachmann 2008)). Even though results from the Nemunas delta have to be treated with care due to the small sample size, this finding indicates that information on distribution of Aquatic Warblers can not be transferred from the large core population to the small Lithuanian population. In the Lower Oder Valley Nationalpark a nest-male distance as large as 250 m was observed (F. Tanneberger, unpublished). In the Nemunas delta all nests were located in distances far below 250 m to the nearest male singing during the nesting period. Thus it is concluded that the largest nest-male distance recorded in this study region will be sufficient for establishing nest-protection zones to be spared from mowing. Buffers installed with a radius of 120 m around each recorded singing male therefore will enable the protection of most of the Aquatic Warbler nests in the Nemunas delta.

The nest area, which is the total area of nest buffers, illustrates the spatial distribution of Aquatic Warbler nests. Thus, sparing this area from mowing safeguards a majority of Aquatic Warbler nests and replaces invasive nest search.

Nest protection via buffers around recorded locations of males to be spared from mowing has previously been recommended for other species. For Corncrakes buffers with a radius of 200-300 m around each calling male are regarded as being sufficient for the protection of nests and activity ranges of young birds (Just 2005).

The cheapest and most feasible procedure in conservation management is the designation of areas to be spared from mowing based on a single Aquatic Warbler singing males count in June. Results of the two succeeding June surveys lead to the conclusion that some singing males will be missed within a single survey (Fig.10 & 11). Still, the proportion of nest area derived additionally from the 2nd June count is small. In Sysa the proportion of nest area during the late brood, derived from the July count, was larger (26 %). Thereby it can be assumed that in 2011 Aquatic Warblers were forced to change meadows due to grassland harvest and that the protection of nest area derived from the singing male survey in the beginning of June might be sufficient in order to safeguard the majority of Aquatic Warbler nests. In addition, grassland harvest in July may limit the options for the integration of biomass as fodder into agricultural systems due to lower fodder quality (Donath et al. 2004). The economical dependency of farmers in the Nemunas delta on meadow harvest therefore enhances the importance of designating the area to be spared from mowing in order to protect Aquatic Warbler nests in the beginning of June.

The proportion of nest area extending into parcels without records of singing males is small (8% of the nest area in Sysa and 0% of the nest area in Sausgalviai). Therefore only the meadows with current records of singing males have to be spared from mowing.

5.4.3 Earliest mowing date for maintaining habitat quality

The eutrophic site conditions in the Nemunas delta imply management recommendations as well in order to maintain habitat quality suitable for the Aquatic Warbler. Soil nutrient availability enhances vegetation productivity and therefore affects the Aquatic Warbler. Early mowing is an effective type of land management in eutrophic floodplain meadows (Olde Venterink et al. 2009), as it prevents increase of standing biomass, reduces vegetation and litter height and creates an open vegetation structure with favourable conditions for the establishment of a variety of species, also of CSR-strategy type (Lepš 1999, Billeter et al. 2007, Pfadenhauer et al. 2001, Gerard et al. 2008, Poptcheva et al. 2010). The proportion of early used land is particularly important for the Aquatic Warbler in the eutrophic floodplain polder habitats (Tanneberger et al. 2008, Tanneberger et al. 2010). A first mowing date later than June favours dominant, dense stands of tall growing species such as tall sedges and rushes (as *Carex vesicaria*, *Glyceria maxima*, *Phalaris arundicancea*, *Calamagrostis cansecens*), which is detrimental to species richness (Poptcheva et al. 2009, Rosenthal and Hölzel 2009). Meadow harvest twice a year without fertilizer application removes considerably more nutrients from soil than mowing once a year, paralleled by a higher decrease of productivity of nutrient demanding vegetation (Oelmann et al. 2009, Poptcheva et al. 2009, Rosenthal and Hölzel 2009). This was even observed in floodplains in areas with high atmospheric N input and formerly high intensity of agricultural land-use (Poptcheva et al. 2009). Therefore in order to maintain a habitat quality suitable for the Aquatic Warbler an earliest mowing date in the beginning of June and two cuts per year are recommended for the parts of the meadows, that are not occupied by Aquatic Warblers. thereby possible negative effects of such an earliest mowing date on chick survival of other bird species breeding in the Nemunas delta, such as Corncrake or Black Tailed Godwit (*Limosa limosa*), have to be considered (Just 2005, Schekkerman & Beintema 2007).

5.5 Conclusion

Findings of the presented study reveal that management actions are urgently needed in order to halt further decline of the Lithuanian Aquatic Warblers population. Especially in the Nemunas delta Aquatic Warbler nests have to be better protected in order to enable a higher breeding success in the future. In addition habitat quality has to be maintained or even improved.

Therefore a flexible mowing scheme is recommended for Aquatic Warbler habitats in the Nemunas delta. This is in accordance with findings from previous studies on Aquatic Warbler habitat in the floodplain meadows of the Lower Oder Valley (Helmecke et al. 2003, Tanneberger et al. 2008, Tanneberger et al. 2010). These habitats are, amongst all remaining Aquatic Warbler breeding sites, the most similar to sites in the Nemunas delta (Tanneberger et al. 2010, own findings).

Meadow harvest in the Aquatic Warbler breeding areas in the Nemunas delta should not start before a first singing males survey has been conducted in the beginning of June. The area within a radius of 120 m around each recorded singing male (GPS-locations) (the nest area, as explained above) has to be spared from mowing until at least August 15th. This will enable the protection of most of early and late Aquatic Warbler nests (100% of all nests found within this study).

For the area not occupied by Aquatic Warblers an early onset of meadow harvest (i.e. in the beginning of June) and mowing twice per year should be facilitated in order to maintain a vegetation structure suitable for the Aquatic Warbler.

Such an alternating mowing system in addition would favour habitat heterogeneity and therefore probably the abundance of prey. Both is beneficial for the occurrence of Aquatic Warblers (Tanneberger 2008, Tanneberger et al. 2010).

It is speculated, that slightly less eutrophic site conditions and a higher breeding success in Tyrai mire indicate that less intensive management is necessary in order to maintain a suitable habitat quality for the Aquatic Warbler. Currently in Tyrai mire Aquatic Warblers only breed in open areas dominated by *Carex disticha.* Their occurrence is assumed to be threatened by the expansion of reedbeds (members of AWCT and BEF, pers. comment). As previous studies showed, in the less productive sites winter mowing might be sufficient to maintain habitat quality suitable for the Aquatic Warbler (Tanneberger et al. 2009, Tanneberger et al. 2010). In the mesotrophic reed sites of Rozwarowo marshes, western Poland, successful Aquatic Warbler broods have been observed in areas dominated by *Phragmites australis*, cut in the previous winter (Tanneberger et al. 2009). On abandoned sites that are heavily overgrown with reed, as it is the case in large parts of Tyrai mire, summer mowing can improve habitat conditions (Tanneberger et al. 2010). Initial intensive summer reed harvest might enlarge the area of habitat suitable habitat for the Aquatic Warbler in Tyrai mire. Regular winter mowing in the parts currently occupied by Aquatic Warblers might be sufficient to maintain a suitable habitat quality, hopefully accompanied by stabilisation of the population size. Such a development is desirable, as maintenance management in the less eutrophic habitats is rather easy to conduct compared to the eutrophic and highly dynamic sedge sites of the Nemunas delta. Here in addition conservation interest conflict with the economical needs of farmers.

Alternative forms of land use could be developed to promote flexible Aquatic Warbler friendly land use in the Nemunas delta. These might be energetic use of the late cut reed canary grass and sedges as well as their industrial use as insulating material (Tanneberger et al. 2010, Wichtmann and Joosten 2007, Timmermann et al. 2009). Additional economic incentives within agri-environmental schemes (AES) are essential in order to make a delayed mowing date for parts of meadows occupied by Aquatic Warblers feasible. The early cut grass of parts of meadows not occupied by Aquatic Warblers will be available for farmers as fodder, of course.

Some of these recommendations are currently already explored and agri-environmental schemes are developed within the EU Life+ project ´Baltic Aquatic Warbler - Securing sustainable farming to ensure conservation of globally threatened bird species in agrarian landscape` (LIFE09 NAT/LT/000233, project duration: 2010-2015). Within the project continued monitoring on habitat quality, meadow harvest and the distribution of Aquatic Warblers is essential. In Tyrai mire further research on habitat conditions (especially soil conditions) is required in order to develop the most appropriate management scheme for this site.

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Eidesstattliche Erklärung

Ich versichere, die vorliegende Diplomarbeit mit dem Titel:

”Habitat use of the Aquatic Warbler (*Acrocephalus paludicola*) in Lithuania 2011”

selbstständig verfasst und keine anderen Hilfsmittel als die angegebenen verwendet zu haben. Aus anderen Werken in Wortlaut oder Sinngehalt entnommene Inhalte sind durch Quellverweis, auch für Sekundärliteratur, als Entlehnung kenntlich gemacht.

Greifswald, den 2.12.2012

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Picture on front page: Aquatic Warbler female with nestlings. Drawing by Benjamin Dalcke from a photo by Zymantas Morkvenas.

Annexes

Annex 1. Londo-scale for recording coverage in vegetation analysis. Coverages are given as the proportion of ground covered (following Londo1976).

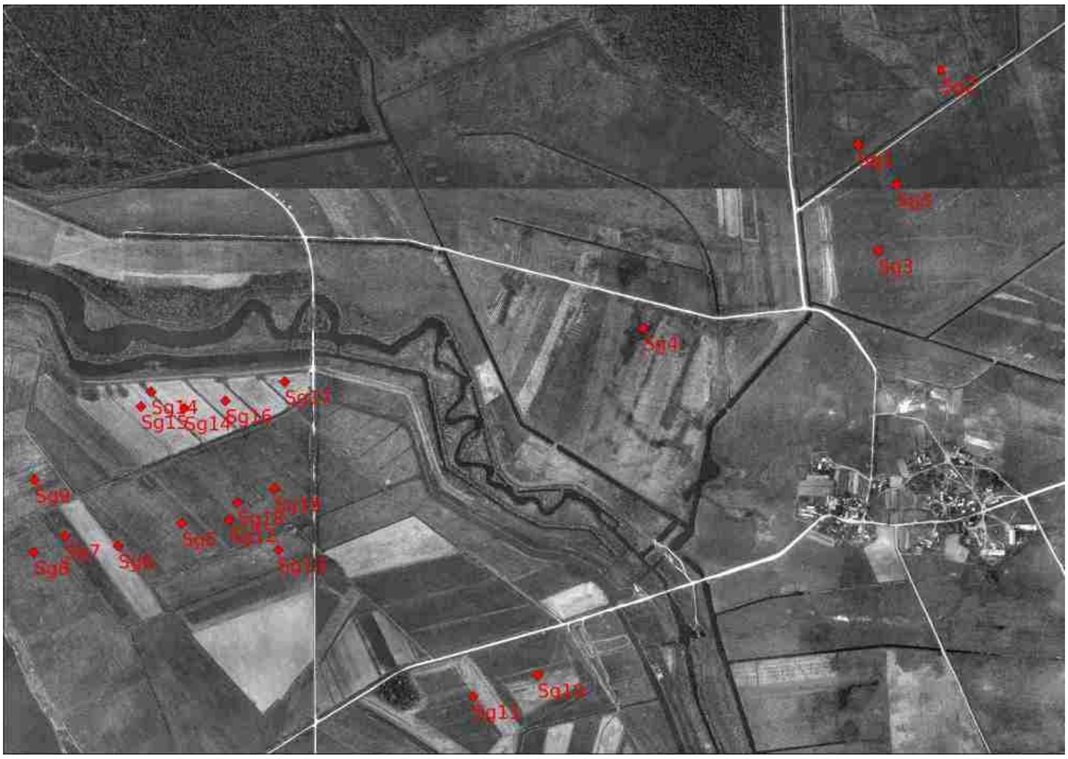
Symbol	Coverage in %	Mean (%)
0.1	< 1	1
0.2	1- 3	2
0.4	4 - 5	4
1	6 - 15	10
2	16 - 25	20
3	26 - 35	30
4	36 - 45	40
5	46 - 55	50
6	56 - 65	60
7	66 - 75	70
8	76 - 85	80
9	86 - 95	90
10	96 - 100	100

Annex 2. Aquatic Warbler singing males in studied areas in 2006 and 2011. NA = Result of singing males survey was not available. Data from BEF and Tanneberger et al. 2010.

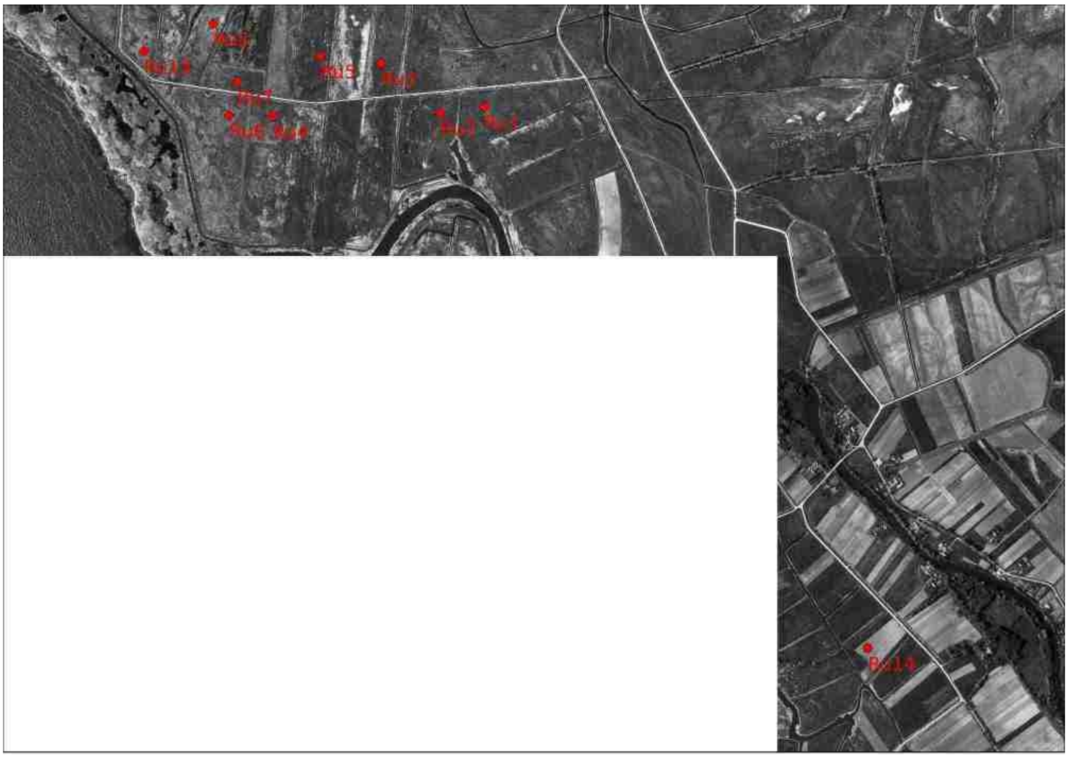
area	Aquatic Warbler singing males 2006	Aquatic Warbler singing males 2011
Sysa	50 - 60	24 - 33
Sausgalviai	14	12 - 13
Rusne (Uostadvaris)	2	7
Minija	0	1 - 3
Sakuciai	0	NA
Svencele	6	0
Tyrai	NA	30 - 45

Annex 3. Study sites Sysa, 2006 & 2011.

Annex 4. Study sites Sausgalviai, 2006 & 2011.



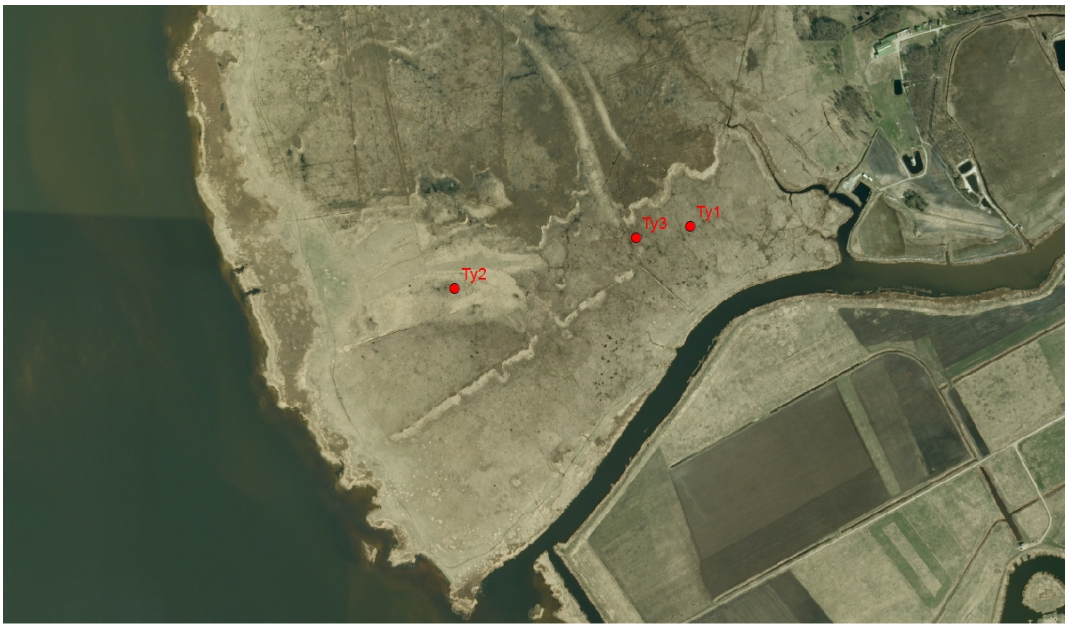
Annex 5. Study sites Rusne, 2006.



Annex 6. Study sites Minija, 2006.

Annex 7. Study sites Sakuciai, 2006.

Annex 8. Study sites Tyrai mire, 2011.



Annex 9. Habitat parameter, Sysa 2011.

site	region	date	Easting	Northing	AW	PH_SO	CN_SO	SPNUM	VEGHEIGHT	WATHEIGHT	SOILMOIS	LITTMEAN	COVWAT	COVSOIL	COVLIT	COVMOSS	COVHERB1	COVHERB2
Sy2	Sy	06/08/2011	21.395916667	55.317222222	0	5.47	12.4	8	106.08	0	3	16.5	1	1	100	1	1.3	87.7
Sy3	Sy	26/05/2011	21.397638889	55.319611111	0	6.40	13.20	2	56.17	5.86	6	30.42	14.7	0	36.7	0	0	56.7
Sy3	Sy	08/07/2011	21.397638889	55.319611111	1	6.40	13.20	4	126.5	0	3	12.25	1	1	93.3	1	1	86.7
Sy3	Sy	07/08/2011	21.397638889	55.319611111	1	6.40	13.20	5	116.91	0	5	11.63	1	1	96.7	1	1	80
Sy4	Sy	26/05/2011	21.400416667	55.314805556	1	5.63	13.65	6	34.3	0	3	20.06	0.3	0.3	46.7	3	10	36.7
Sy4	Sy	26/05/2011	21.400083333	55.315138889	1	5.63	13.65	4	39.79	0.77	6	26.91	1.3	1.3	36.7	0	1.3	56.7
Sy4	Sy	08/07/2011	21.400083333	55.315138889	1	5.63	13.65	9	91.83	0	3	18.83	1	1	86.7	1	6	90
Sy5	Sy	26/05/2011	21.401083333	55.320805556	1	5.73	13.60	3	57.21	0	4	22.53	0	3	13.3	0	1	86.7
Sy5	Sy	25/06/2011	21.401083333	55.320805556	0	5.73	13.60	8	101.75	0	3	20.125	1	1.3	76.7	1	4	96.7
Sy6	Sy	26/05/2011	21.401583333	55.320138889	1	5.86	13.60	6	58.29	0	3	24.29	0	6.7	36.7	0	0	60
Sy6	Sy	22/06/2011	21.401583333	55.320138889	1	5.86	13.60	7	95.92	0	3	11.75	1	1	86.7	1	1	86.7
Sy7	Sy	27/05/2011	21.406083333	55.323694444	1	5.31	13.8	6	65.73	0	3	9.04	1	13.3	11.3	1	2	80
Sy7	Sy	25/06/2011	21.406083333	55.323694444	1	5.31	13.8	4	100	0	2	4	1	1	60	1	4	86.7
Sy8	Sy	27/05/2011	21.406083333	55.317805556	1	5.65	11.70	4	65.61	6.53	6	34.98	7.3	1	63.3	1	1	30
Sy8	Sy	27/05/2011	21.401083333	55.319416667	1	5.65	11.70	4	51.07	0	4	26.71	1	1	83.3	1	1	20
Sy8	Sy	27/05/2011	21.406083333	55.320972222	1	5.65	11.70	5	59.98	0	3	20.33	1	73.3	13.3	1	2	80
Sy8	Sy	22/06/2011	21.401083333	55.319416667	1	5.65	11.70	4	76	0	3	15.83	1	1	93.3	1	1.3	83.3
Sy8	Sy	22/06/2011	21.406083333	55.320972222	1	5.65	11.70	7	114.29	0	2	12.75	1	1	86.6	1	3	93.3
Sy8	Sy	06/08/2011	21.406083333	55.317805556	1	5.65	11.70	8	108.42	0.67	5	19	4	1	96.7	1	1.3	80
Sy8	Sy	29/06/2011	21.401083333	55.321888889	1	5.65	11.70	4	119.75	0	2	10.28	1	1	95	3.25	4	97.5
Sy9	Sy	23/06/2011	21.407888889	55.324277778	1	5.19	14.4	11	107.67	0	3	11.88	1	1	86.7	1	2	96.7
Sy9	Sy	31/07/2011	21.407888889	55.324277778	1	5.19	14.4	12	105.88	0	4	15.75	1	1	90	1	1.3	90
Sy9	Sy	29/06/2011	21.407194444	55.324416667	1	5.19	14.4	7	89.19	0	3.33	16.02	1	1	52.7	1	2.3	84.5
Sy10	Sy	23/06/2011	21.408277778	55.322472222	0	5.55	16.8	7	88.75	0	4	16.46	1	1	90	1	2	76.7
Sy10	Sy	29/06/2011	21.408055556	55.322416667	1	5.55	16.8	7	90.56	0	3.44	16.99	3.1	1	100	1	2	45.6
Sy11	Sy	30/05/2011	21.401083333	55.318277778	1	5.46	15.5	6	67.33	0	4	26.67	1	4	66.7	1	1.3	80
Sy11	Sy	08/07/2011	21.401083333	55.318277778	1	5.46	15.5	8	101.33	0	3	23.58	1	1	90	1	4	93.3
Sy11	Sy	12/08/2011	21.401083333	55.318277778	1	5.46	15.5	8	86.17	4.08	6	15.08	5	1	80	1	1	86.7
Sy12	Sy	31/05/2011	21.412972222	55.320583333	0	5.66	15.5	7	64	0	5	29.25	1	1	80	1	4	70
Sy12	Sy	09/07/2011	21.412972222	55.320583333	0	5.66	15.5	9	114.58	0	4	26.5	1	1	100	1	1	96.7
Sy12	Sy	11/08/2011	21.412972222	55.320583333	0	5.66	15.5	8	102.08	0.04	5	5	1	1	100	1	1.3	90
Sy13	Sy	30/05/2011	21.416861111	55.320861111	1	5.66	15.5	5	32.5	0	4	30	1	1	90	1	1	30
Sy13	Sy	09/07/2011	21.416861111	55.320861111	0	5.66	15.5	10	90.5	0	3	20.58	1	1	100	1	2.3	80
Sy13	Sy	09/08/2011	21.416861111	55.320861111	0	5.66	15.5	13	90.17	0	4	3.92	1	1	96.7	1	3.3	80
Sy14	Sy	30/05/2011	21.406083333	55.321472222	0	5.22	17.6	5	45.42	0	4	7.33	1	4.7	33.3	1	1.7	80
Sy14	Sy	01/07/2011	21.406083333	55.321472222	0	5.22	17.6	7	113.75	0	3	7.79	1	1	90	1	6	96.7
Sy15	Sy	31/05/2011	21.419055556	55.323527778	0	5.68	14.80	4	62.79	20.04	6	21.04	1	30	56.7	1	8	60
Sy16	Sy	31/05/2011	21.421833333	55.321666667	0	5.63	16.00	4	41.29	0	4	6.92	1	1.7	53.3	1	25	23.7
Sy17	Sy	29/05/2011	21.406083333	55.31925	1	5.31	12.30	5	54.83	1.13	5	29.79	1	1.3	40	1	1	73.3
Sy17	Sy	27/06/2011	21.406083333	55.31925	1	5.31	12.30	8	88.33	0	3	16.67	1	1	100	1	7.3	100
Sy17	Sy	29/06/2011	21.401083333	55.31975	1	5.31	12.30	10	75.02	0	4.17	17.07	1	1	100	1	2.1	85.6
Sy18	Sy	29/05/2011	21.401083333	55.31925	1	5.31	12.30	4	43.73	0	3	24.36	1	1	73.3	1	1	40
Sy18	Sy	30/06/2011	21.401083333	55.31925	1	5.31	12.30	7	83.03	0	3	22.08	1	1	100	1	5	93.3
Sy19	Sy	10/07/2011	21.406083333	55.313972222	1	5.31	12.30	9	99.83	0	3	14.25	1	1	100	1	5.3	86.7
Sy21	Sy	03/07/2011	21.414916667	55.317111111	0	5.80	14.9	11	101	0	3	20.33	1	1	100	1	3.3	93.3
Sy22	Sy	08/06/2011	21.434694444	55.322583333	1	5.54	12.20	13	63.71	0	3	9.42	1	1	83.3	1	4	83.3
Sy23	Sy	08/06/2011	21.433694444	55.326555556	0	5.30	13.80	13	70.46	0	3	12.58	1	2.7	36.7	1	3	86.7
Sy24	Sy	01/06/2011	21.426972222	55.329694444	0	5.1	13.0	8	59.66	0	4	17.63	1	4	46.7	1	7.3	76.7
Sy25	Sy	01/06/2011	21.427	55.329694444	0	5.1	13.0	11	58.21	0	3	2.42	1	2.3	11.3	1	46.7	60
Sy25	Sy	04/07/2011	21.427	55.329694444	1	5.1	13.0	10	101.92	0	3	6.17	1	1	86.7	1	14.7	90
Sy26	Sy	01/06/2011	21.423111111	55.330583333	1	5.06	13.4	9	49.5	0	3	20.71	1	1	70	1	10.3	50
Sy26	Sy	07/07/2011	21.423111111	55.330583333	1	5.06	13.4	14	87.83	0	3	20.63	1	1	96.7	1	8.3	83.3
Sy27	Sy	03/07/2011	21.430527778	55.330944444	1	5.09	12.4	10	93.75	0	3	8.54	1	1	96.7	1	10.7	90

Annex 10. Habitat parameter, Sausgalviai & Tyrai mire 2011.

site	region	date	Easting	Northing	AW	PH_SO	CN_SO	SPNUM	VEGHEIGHT	WATHEIGHT	SOILMOIS	LITTMEAN	COVWAT	COVSOIL	COVLIT	COVMOSS	COVHERB1	COVHERB2
Sg1	Sg	28/05/2011	21.462777778	55.27975	1	5.55	13.4	6	48.83	0	4.08	16.75	1	86.7	23.3	1	3	76.7
Sg1	Sg	28/05/2011	21.464	55.282333333	1	5.59	14.7	5	45.29	0	4.42	12.58	1	1	56.7	1	1.3	76.7
Sg1	Sg	29/06/2011	21.464	55.282333333	1	5.59	14.7	15	89.08	0	4	12	1	1	100	1	23.3	100
Sg1	Sg	30/07/2011	21.464	55.282333333	1	5.59	14.7	17	90.13	0	4	14	1	1	91.7	1	23.3	80
Sg1	Sg	28/05/2011	21.463388889	55.285583333	0	5.61	14.7	11	45.33	0	3	21.29	1	1	83.3	1	13.3	86.7
Sg1	Sg	29/05/2011	21.4625	55.283972222	0	5.49	13.9	8	23	0	4	3.46	1	1	83.3	1	66.7	26.7
Sg2	Sg	29/05/2011	21.468944444	55.283388889	1	5.79	14.5	13	30.08	0	3	6.83	1	2.3	34	1	50	50
Sg2	Sg	29/05/2011	21.468638889	55.288361111	1	5.62	13.8	12	62.88	0	4	5.62	1	23.7	33.3	1	20	83.3
Sg2	Sg	28/06/2011	21.468944444	55.283388889	1	5.79	14.5	18	52	0	3	2.08	1	1	44.7	1	60	50
Sg2	Sg	01/08/2011	21.468944444	55.283388889	1	5.79	14.5	19	72.29	0	3	2.88	1	1	63.3	1	43.3	63.3
Sg2	Sg	01/08/2011	21.466666667	55.284833333		5.79	14.5	19	61.71	0	3	10.555	1	1	58.9	1	5	81.1
Ty1	Ty	26/06/2011	21.228611111	55.528611111	1	5.3	16.5	5	76	0	3	8.67	1	1	100	1	8.7	86.7
Ty1	Ty	14/08/2011	21.228611111	55.528611111	1	5.3	16.5	5	85.96	0	5	8.25	1	1	96.7	1	1	86.7
Ty2	Ty	14/08/2011	21.219861111	55.528555556	1	4.94	14.7	9	84.96	0	5	10.08	1	1	100	7.7	46.7	46.7
Ty3	Ty	14/08/2011	21.226611111	55.529805556	1	4.98	18.2	5	77.08	0	5	6.08	1	1	100	1	1.3	83.3

Annex 11. Organic matter content determined from soil samples collected in 2011.

Study site	Organic matter content (%)
Sy2	24,69
Sy7	39,28
Sy9	57,72
Sy10	45,5
Sy11	60,78
Sy12	71,11
Sy14	76,34
Sy25	53,58
Sy26	50,83
Sy27	36,96
Sg1-1	53,44
Sg1-2	75,78
Sg1-3	76,72
Sg1-4	68,4
Sg2-1	71,52
Sg2-2	74,65
Ty1	74,55
Ty2	67
Ty3	85,35

Annex 12. Predictor variables of candidate models for the dataset collected in late May/ early June in Lithuania in 2006 and 2011.

Selection of predictor variables was based on parameters previously identified as crucial in Aquatic Warbler habitat selection. In case of Spearman rank correlations of or exceeding 0.7 predictors were tested in separate models.

model	predictor variables
1	water height
2	intercept-only
3	vegetation height + litter height + lower herb cover + upper herb cover + water height
4	vegetation height
5	lower herb cover
6	vegetation height + litter height + lower herb cover + upper herb cover
7	soil moisture
8	litter height
9	species number
10	upper herb cover
11	vegetation height + litter height + lower herb cover + upper herb cover + soil moisture
12	cover litter + cover lower herb layer + cover upper herb layer + cover open soil + cover open water
13	vegetation height + litter height + species number + cover upper herb layer + soil moisture

Annex 13. Predictor variables of candidate models for the complete dataset collected in Lithuania in 2006 and 2011.

Selection of predictor variables was based on parameters previously identified as crucial in Aquatic Warbler habitat selection. In case of Spearman rank correlations of or exceeding 0.7 predictors were tested in separate models.

model	predictor variables
1	water height
2	Intercept
3	litter height
4	lower herb cover
5	vegetation height
6	soil moisture
7	day + water height + day:water height
8	upper herb cover
9	species number
10	day + vegetation height + day:vegetation height
11	day + vegetation height + litter height + lower herb cover + day:vegetation height
12	day + vegetation height + litter height + lower herb cover + soil moisture + water height + day:vegetation height
13	day + upper herb cover + litter height + lower herb cover + soil moisture + water height + day:upper herb cover
14	day + upper herb cover + litter height + species number + soil moisture + water height + day:upper herb cover
15	day + vegetation height + litter height + species number + soil moisture + water height + day:vegetation height
16	day + cover litter + lower herb cover + upper herb cover + cover open soil + cover open water + day:cover of upper herb layer

Annex 14. Bivariate Spearman-rank correlation coefficients between predictor variables for the reduced dataset (data collected in late May/ early June). Correlation coefficients ρs ≥ 0.7 are shaded in grey.

	vegetation height	water height	soil moisture	litter height	cover water	cover soil	cover litter	lower herb cover	upper herb cover
species number	-0.03	-0.27	-0.3	-0.48	-0.2	0.12	-0.33	0.59	0.11
vegetation height		0.24	0.32	0.34	0.26	0.09	0.03	-0.5	0.49
water height			**0.72**	0.21	-0.66	0.19	0.07	-0.38	-0.08
soil moisture				0.23	0.57	-0.03	0.14	-0.4	0.01
litter height					0.23	-0.2	0.67	-0.65	0.06
cover water						0.09	0.3	-0.33	0.09
cover soil							-0.07	0.09	0.15
cover litter								-0.33	-0.2
lower herb cover									-0.36

Annex 15. Bivariate Spearman-rank correlation coefficients between predictor variables for the complete dataset. Correlation coefficients ρs ≥ 0.7 are shaded in grey.

	vegetation height	water height	soil moisture	litter height	cover water	cover soil	cover litter	lower herb cover	upper herb cover
species number	0.1	-0.24	-0.24	-0.35	-0.12	0.14	-0.05	0.56	0.14
vegetation height		-0.01	0.06	0.32	0.37	0.18	0.57	-0.41	**0.72**
water height			0.68	0.16	0.57	-0.19	-0.13	-0.33	-0.19
soil moisture				0.15	0.45	-0.04	-0.02	-0.34	-0.14
litter height					0.23	-0.12	0.51	-0.61	0.17
cover water						0.12	0.37	-0.33	0.22
cover soil							0.08	0.06	0.22
cover litter								-0.29	0.39
lower herb cover									-0.34

Annex 16. Aquatic Warbler singing males-coordinates, Sysa 2011.

site	Easting	Northing
1st count		
Sy5	21.40125	55.32178
Sy6	21.40136	55.31633
Sy6	21.40253	55.31944
Sy8	21.40467	55.31997
Sy7	21.40514	55.32331
Sy9	21.40736	55.32344
Sy11	21.40878	55.31856
Sy13	21.41533	55.32181
Sy18	21.41933	55.31983
Sy18	21.42056	55.31836
Sy18	21.42189	55.31775
Sy26	21.42192	55.33047
Sy18	21.42236	55.31583
Sy17	21.42408	55.31928
Sy26	21.42503	55.33058
Sy26	21.42514	55.3315
Sy22	21.43428	55.32275
Sy22	21.43583	55.32211
Sy22	21.43739	55.31994
2nd count		
Sy6	21.40144	55.31622
Sy6	21.40175	55.31769
Sy5	21.40203	55.32233
Sy6	21.40214	55.3195
Sy7	21.40508	55.32308
Sy8	21.40519	55.32092
Sy11	21.40861	55.31861
Sy13	21.41694	55.32111
Sy18	21.41986	55.31933
Sy26	21.42203	55.33006
Sy18	21.42319	55.31575
Sy26	21.42353	55.33133
Sy17	21.42364	55.31919
Sy22	21.43453	55.32281
Sy22	21.43477	55.32
Sy22	21.43764	55.32136
3rd count		
Sy2	21.39456	55.31936
Sy18	21.3975	55.32028
Sy4	21.39911	55.31786
Sy6	21.40139	55.31944
Sy7	21.40414	55.32389
Sy8	21.40489	55.32022
Sy8	21.40569	55.32144
Sy8	21.40669	55.31958
Sy9	21.40764	55.32372
Sy11	21.40844	55.31811
Sy25	21.41072	55.33008
Sy17	21.42042	55.31958
Sy18	21.42119	55.31619
Sy18	21.42133	55.31589
Sy26	21.42192	55.33047
Sy18	21.42328	55.31553
Sy18	21.42392	55.31956
Sy18	21.42425	55.31478
Sy26	21.42514	55.3315

Annex 17. Aquatic Warbler singing males-coordinates, Sausgalviai 2011.

site	Easting	Northing
1st count		
Sg	21.46278	55.28619
Sg	21.46144	55.28697
Sg	21.46447	55.28339
Sg	21.46447	55.28269
Sg	21.46486	55.28164
Sg	21.46675	55.28586
Sg	21.46625	55.28697
Sg	21.46944	55.29797
Sg	21.46594	55.28531
Sg	21.46447	55.28689
2nd count		
Sg	21.46572	55.28497
Sg	21.46825	55.28414
Sg	21.46806	55.28464
Sg	21.46717	55.28564
Sg	21.46697	55.28678
Sg	21.46378	55.28083
Sg	21.46356	55.28197
Sg	21.46447	55.28639
Sg	21.46389	55.28533
Sg	21.46489	55.28144
3rd count		
Sg	21.46611	55.28481
Sg	21.46497	55.28208
Sg	21.46539	55.28636
Sg	21.46536	55.28567
Sg	21.46361	55.28228
Sg	21.46361	55.28328
Sg	21.46897	55.28647
Sg	21.46758	55.28597
Sg	21.46764	55.28528
Sg	21.46803	55.28442

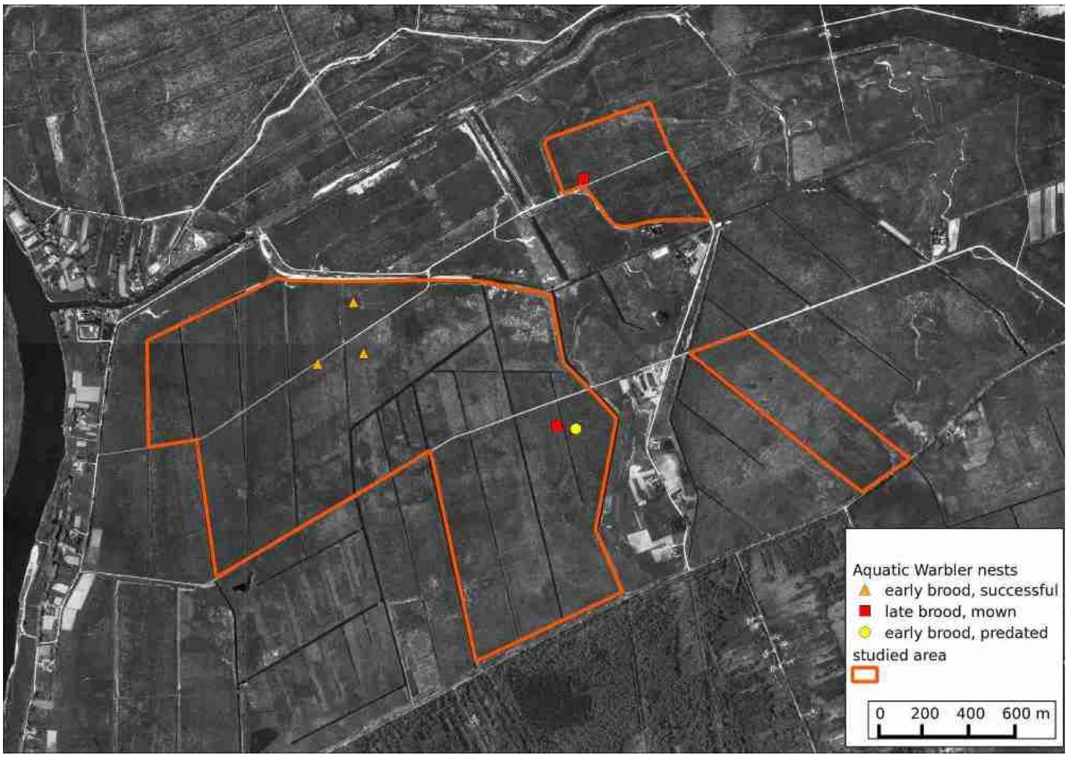
Annex 18. Overview of Aquatic Warbler nests found in Lithuania (Sysa, Sausgalviai & Tyrai mire), 2011.

id	location	date found	content	calculated lay date	(calculated) hatching date	(calculated) fledging date	nr. fledglings
1	Sy 17	09.06.	5 eggs	01.06.11	14.06.11	depredated	0
2	Ty	10.06.	5 nestlings (5 days), 1 egg	21.05.11	04.06.11	18.06.11	5
3	Ty	11.06.	6 nestlings (7 days)	21.05.11	04.06.11	18.06.11	6
4	Sy 9	13.06.	6 nestlings (8 days)	23.05.11	06.06.11	18.06.11	4
5	Sy 10	15.06.	4 nestlings (7 days), 2 eggs	25.05.11	08.06.11	21.06.11	4
6	Sg 2	16.06.	5 nestlings (6 days)	25.05.11	08.06.11	21.06.11	5
7	Sy 8	19.06.	5 nestlings (12 days)	25.05.11	08.06.11	21.06.11	5
8	Sy 18	05.07.	5 eggs	28.06.11	12.07.11	mown	0
9	Sg 1	07.07.	4 eggs	26.06.11	10.07.11	23.07.11	4
10	Sy 26	13.07.	4 eggs	NA	mown	mown	0
11	Ty	19.07.	5 eggs	06.7.11	20.07.11	03.08.11	3
12	Ty	19.07.	2 nestlings, 3 eggs	29.06.11	13.07.11	27.07.11	2
13	Ty	25.07.	5 nestlings	03.7.11	17.07.11	depredated	0
14	Ty	26.07.	5 nestlings	30.06.11	14.07.11	28.07.11	5
15	Ty	28.07.	4 nestlings (7 days)	02.7.11	16.07.11	30.07.11	4

Annex 19. Aquatic Warbler nests-coordinates.

nest_id	location	Northing	Easting
1	Sysa 2a	55.31975	21.42286
2	Tyrai	55.53019	21.22981
3	Tyrai	55.53058	21.22878
4	Sysa 5a	55.32442	21.40722
5	Sysa 5b	55.32242	21.40806
6	Sausg. 2	55.28483	21.46661
7	Sysa 1e	55.32194	21.40492
8	Sysa 2b	55.31983	21.42153
9	Sausg. 1	55.28136	21.46344
10	Sysa 3c	55.32961	21.42275
11	Tyrai	55.52722	21.22414
12	Tyrai	55.52856	21.21969
13	Tyrai	55.52892	21.23042
14	Tyrai	55.52864	21.21908
15	Tyrai	55.5293	

Annex 20. Location of Aquatic Warbler nests, Sysa 2011.



Annex 21. Location of Aquatic Warbler nests, Sausgalviai 2011.

Annex 22. Location of Aquatic Warbler nests, Tyrai mire 2011.