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Decline of Long-tailed Duck *Clangula hyemalis* numbers in the Pomeranian Bay revealed by two different survey methods

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Abundance of Long-tailed Ducks *Clangula hyemalis* wintering in the Pomeranian Bay was monitored between 1988 and 2014, using both ship-based and aerial surveys and correcting for distance dependent detection. Aerial surveys were conducted using an improved transect division and a double observer design to estimate detection probability near the transect line. As the latter probability was considerably below 1, we applied an additional correction factor for observer efficiency. After correcting for observer efficiency in aerial surveys, the two methodological approaches yielded similar densities, though an apparent underestimation in aerial surveys warrants further cross-validation. Density estimates from both platforms were merged for further analysis. After reaching peak levels in 1992 and 1993, Long-tailed Duck winter densities in the Pomeranian Bay declined by 82% until 2010. This decline was part of an overall decline in numbers throughout the Baltic Sea. An apparent increase since 2010, which was likely due to local ice-induced movements, indicates that habitats in the study area may still support high densities today.

1. Introduction

The Baltic Sea is one of the largest brackish water bodies in the world, supporting several million seaducks during the non-breeding season (Durinck *et al*. 1994, Skov *et al*. 2011). In winter, more than 90% of the staging seaducks can be found within areas covering less than 5% of the Baltic Sea. The most important areas for seaducks in the Baltic have been identified in shallow coastal waters and in the vicinity of shallow offshore banks where diving birds can easily reach their preferred prey, benthic bivalves (Kube & Skov 1996). The Pomeranian Bay in the Southern Baltic Sea (Fig. 1), together with the adjacent inner coastal lagoons, is one of the three most important

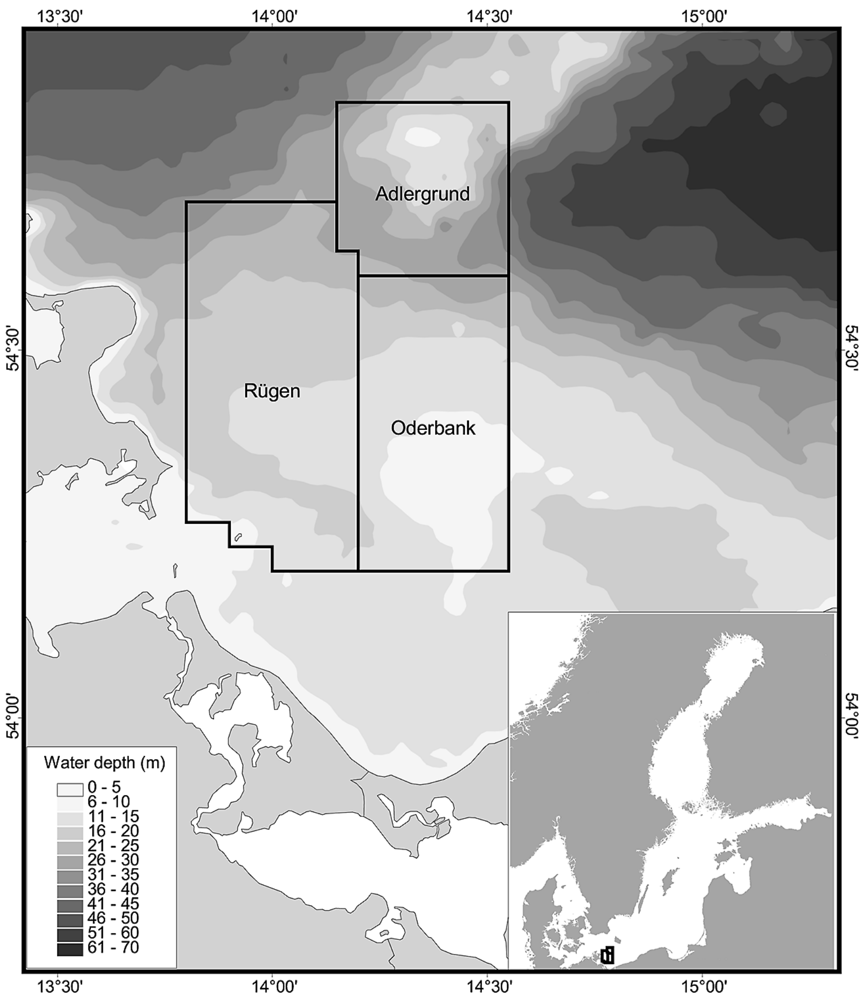

Fig. 1. Map of the Pomeranian Bay with depth contours showing the three survey areas.

areas for waterbirds in the Baltic Sea (Skov *et al.* 2011).

Throughout the northern hemisphere, many seaduck populations are currently in decline (Wetlands International 2012). In the Baltic Sea, numbers of wintering seaducks have decreased by approximately 60% between 1993 and 2008 (Skov *et al.* 2011). Total numbers of the most abundant species, the Long-tailed Duck *Clangula hymealis*, decreased in the Baltic by 65% from 4,272,000 birds in 1992–1993 to 1,482,000 birds in 2007–2009.

These totals are based on two large-scale surveys of wintering waterbirds covering most of the ice-free shallow waters of the entire Baltic Sea in late winter and early spring (Durinck *et al.* 1994, Skov *et al.* 2011). Since no other comprehensive surveys were conducted between 1994 and 2007, it remains unclear if this decline was continuous from 1994 until today, and if it affected preferred and less preferred wintering sites in the same way. Detailed analyses of regional surveys in major staging areas might help to answer these questions. In this paper we use repeated surveys in core areas of the Pomeranian Bay to study changes in Long-tailed Duck densities from 1988 until 2014.

Two approaches have been widely used for counting seabirds in the Baltic. Ship-based line transects are a well-developed method and especially suitable to obtain reliable density estimates (Tasker *et al.* 1984). Aerial visual surveys offer a cost-efficient alternative because they enable much larger areas to be covered per day, including shallow waters where ships cannot operate (Buck-

Table 1. Definition of transect bands used for aerial surveys

Band	Below aircraft (invisible)	A	B	C
Published standard				
Outer bound (degrees)	60	25	10	–
Outer bound (m from transect line)	44	163	431	–
Band width (m)	–	119	268	–
New division since 2006				
Outer bound (degrees)	60	25	15	10
Outer bound (m from transect line)	44	163	284	431
Band width (m)	–	119	121	147

land *et al*. 2012). Results obtained with the current standardised methods for the two approaches (Camphuysen *et al*. 2004) have, however, not been cross-validated yet. Hence we also tested for variation in the density estimates due to methodological approach.

2. Methods

2.1. Study area

The Pomeranian Bay is located between the German islands of Rügen and Usedom in the West, the Polish coast in the South and the Danish island of Bornholm in the Northeast. Characteristic features are the large shallow waters around the Oderbank and the Adlergrund at its north-western end. These shallow waters form the main wintering habitat for seaducks. To deal with variable survey coverage, we subdivided the study area into three parts, characterised by shallow waters around the Oderbank, the Adlergrund, and the moderately deep waters east of Rügen, respectively (Fig. 1).

2.2. Seaduck surveys

During 1988–1993 seaducks were counted from ships, using standard transect survey techniques (Durinck *et al*. 1994). Since 2003 we conducted both ship-based and aerial seabird surveys repeatedly along pre-defined, parallel transect lines, thus achieving a comparatively constant effort and coverage. The timing and coverage of surveys is shown in table S1 and figure S1 in the supplement (see the journal's web site).

All ship-based surveys followed the standards detailed by Webb & Durinck (1992) and Camphuysen *et al*. (2004), using a 300 m wide line-transect and usually two observers on one side of the vessel in areas holding large numbers of seaducks.

The observers regularly searched several hundred meters ahead the vessel using binoculars for birds swimming or reacting on the approaching vessel. Platform positions were recorded at regular intervals either manually or automatically using a GPS.

Aerial counts were performed using 387 m wide line transects from an aircraft equipped with bubble windows flying at an altitude of approximately 76 m (250 ft.) and 180 km/h (100 kts) speed (Noer *et al*. 2000, Camphuysen *et al*. 2004). Weather conditions (sea state, visibility, glare) were recorded and data were only included if sea state did not exceed a limit of 3 on the Beaufort scale. The transect was divided into distance bands using an inclinometer. From 2006 onwards, we subdivided the outer band at 284 m from the transect line, resulting in three bands of approximately equal width (Table 1) similar to the division used by Buckland *et al*. (2012). Since 2006 a second observer, seated behind the primary observer, recorded birds within the inner band A to estimate detection probability of birds close to the transect line.

All observations relating to species, number, behaviour (swimming, diving), transect band and time were continuously recorded on digital voice recorders at the accuracy of one second, giving information on. A GPS recorded flight tracks at intervals (2003–2004: 5 seconds, 2006–2007: 2 seconds, 2010–2012: one second), resulting in spatial resolutions varying from 50 m to 250 m.

Table 2. ESW model results from DISTANCE (n = 2,155 data sets; half normal key function; MCDS engine)

Variables included	No. param.	Delta AIC	Evidence ratio
Observer, flock size	5	0.0	1
Observer, sea state, flock size	7	1.1	1.7
Observer, flock size, glare	8	3.2	5.0
Observer, sea state	6	4.8	11.0
Observer	4	4.8	11.0
Observer, sea state, flock size, glare	10	5.6	16.4

2.3. Distance-dependent detection

The detectability of seabirds decreases with increasing distance from the survey platform resulting in an effective strip width (ESW) which is smaller than the total transect width (Buckland *et al*. 2001). We estimated ESW for ship-based surveys separately for sea states 0–2.5 and 3–4, and flock sizes of 1–10 and 11–50 birds, respectively, using the software package DISTANCE and a half normal model which showed the best fit to the data (Thomas *et al*. 2010).

For aerial surveys we used observations obtained from 2006 onwards to estimate ESW. We performed model selection on a set of models containing different combinations of explanatory variables (Table 2). Model fit was assessed using AIC. Considering only models with delta AIC < 2, we estimated ESW for different observers, sea states (1–3), and flock sizes of 1–2, 3–5, and 6–30 individuals. Estimates ranged from 118 to 170 m (Table S2 in the supplement). A correction for larger flocks was not performed.

2.4. Observer efficiency in aerial surveys

In order to test the assumption that detection probability close to the transect line equals 1 (Bächler & Liechti 2007), we introduced the double-observer design in 2006 to estimate observer efficiency for band A. We estimated observer efficiency in the Mark-Recapture Distance Sampling (MRDS) engine in DISTANCE 6.0, including effects of observer, sea state and flock size according to the ESW model results (Thomas *et al*. 2010). The software estimates the total number of flocks and the number of flocks observed by each observer. From these estimates we obtained a correction factor for each primary observer by dividing the total number of flocks by the number recorded by the observer. Observers detected 35–92% of flocks, leading to correction factors of 1.1–2.8 (Table S3 in the supplement). Finally, we applied ESW and the correction for observer efficiency to all observations from aerial surveys, including those from 2003–2004 when the original transect division was used.

2.5. Aerial vs. ship surveys

We compared corrected densities from ship-based and aerial counts for all occasions when surveys using the different platforms were conducted within the same month. The difference between the paired density values was standardized by the total density as the relative difference

$$\Delta D_{rel} = \frac{D_s - D_a}{D_s + D_a}$$

with D_s = density after ship survey and D_a = density after aerial survey.

2.6. Trend analysis

We chose a generalized additive mixed model (GAMM) with the three survey units as random effect to estimate a smoothed trend of bird densities as a function of year and season. A platform effect was included to investigate if an effect of aerial surveys on density remained after the improved correction. Models were fitted in R 2.15.0 (R Development Core Team 2012) with the package mgcv (Wood 2006) using thin plate regression splines, a logarithmic link and a quasi-Poisson error distribution. To assess model fit, diagnostic plots of the residuals and observed against fitted values were checked (Zuur *et al.* 2009).

3. Results

3.1. Aerial vs. ship surveys

On 12 occasions the two different platforms were used to conduct surveys within the same month and the same area, with an average period of 10

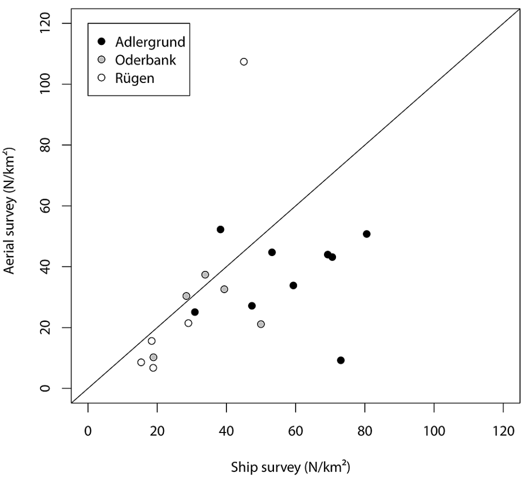

Fig. 2. Long-tailed Duck density estimates from aerial surveys versus density from ship-based surveys conducted within 1–17 days. The straight line indicates equal densities.

days between the paired surveys (extreme values 1–17). The resulting 19 paired density estimates were strongly correlated (Fig. 2). A simple linear model with $R^2 = 0.7$ and $p < 0.001$ showed a relationship between the two platforms of

Aerial density = 0.70 (SE 0.11) × Ship density

The mean standardized relative difference was 0.17 for data from 2003–2004 and 0.18 for data from 2006 onwards, respectively.

3.2. Trend and seasonal occurrence

Long-tailed Duck densities showed an apparently continuous decline after 1993 up until at least 2010 throughout the study area (Fig. 3a). During the course of the winter, densities were highest from January until the onset of spring migration in late March (Fig. 3b). Mean winter (January–March) densities in the entire study declined by 82 %, from 162.8 birds per km² in 1992–1993 to 28.6 in 2006–2012.

The smoothed temporal trend from the GAMM showed a steady decline during the period 1993–2010 and increases before and afterwards (Fig. 4), while a smoothed seasonal trend predicted maximum densities in February (Days 32–59). No significant effect of the survey platform was detected by the model (Table 3). Residual plots showed a reasonable model fit and no autocorrelation (Fig. S2 and S3 in the supplement).

4. Discussion

4.1. Changes in Long-tailed Duck numbers

The density of Long-tailed Ducks showed a steep decline over a period of 18 years in one of its most important wintering areas in the Baltic Sea, the Pomeranian Bay. Declines occurred in the preferred habitat, the shallow waters in the vicinity of

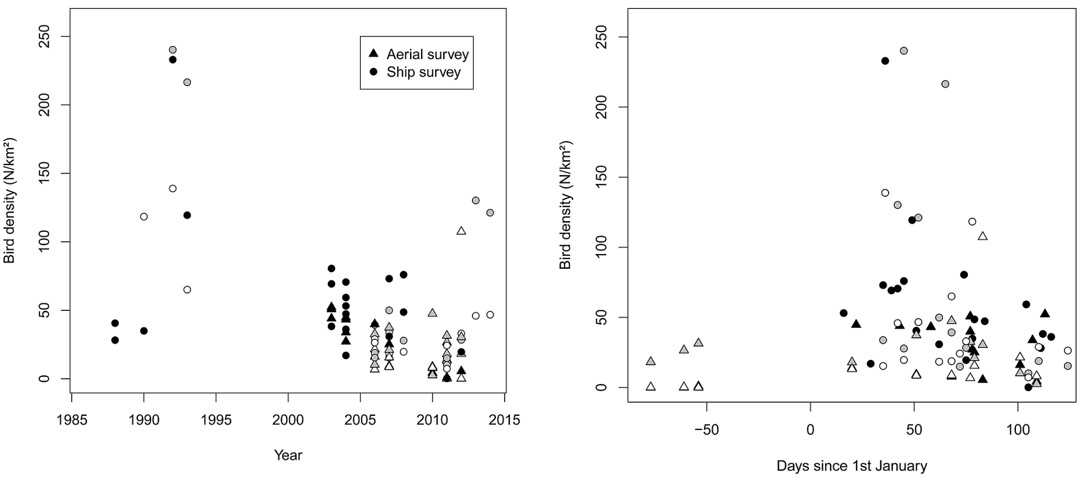

Fig. 3. Mean densities of Long-tailed Ducks from ship-based and aerial surveys (left) between 1988 and 2012 and (right) the seasonal occurrence. Colours represent different areas: black = Adlergrund, grey = Oderbank, open = Rügen.

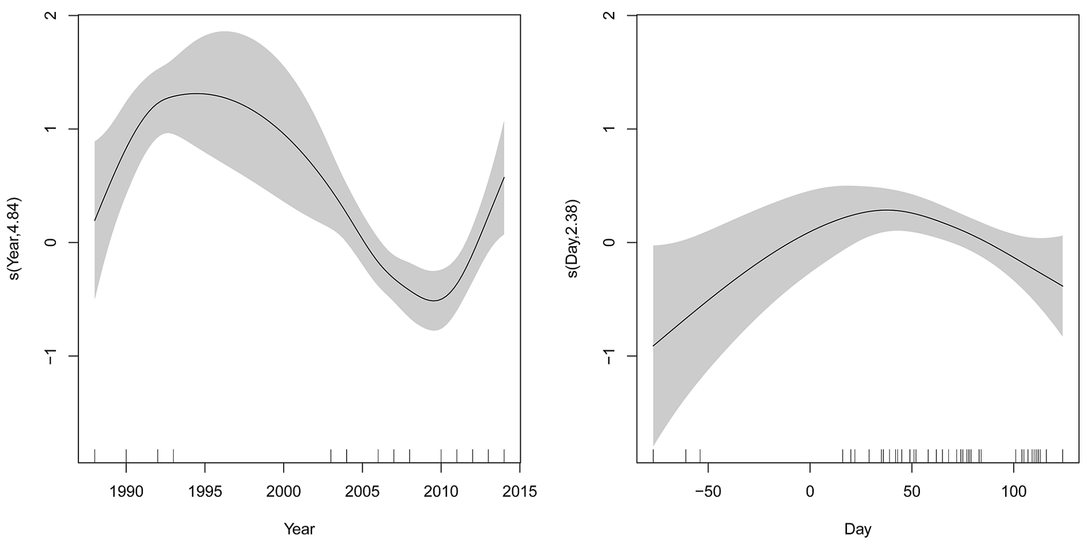

Fig 4. Estimated smoothing curves with 95% confidence intervals for Long-tailed Duck densities shown in Fig. 3.

the banks Oderbank and Adlergrund, as well as in the peripheral western part (this study) and along the coast of Usedom (Bellebaum *et al*. 2013). This fits with the presence of an equal harvestable food supply (especially the bivalves *Mya arenaria* and *Mytilus* spp.) throughout the Pomeranian Bay at water depths of less than 20 m (Kube & Skov 1996). Lower densities of Long-tailed Ducks in the western part of the Pomeranian Bay are attributable to a combined effect of water depths greater than 20 m and higher shipping intensity in the West (Kube & Skov 1996, Bellebaum *et al*. 2006, Schwemmer *et al*. 2011). The only other long-term data set from another of the species' major wintering areas in the Baltic, the Hoburgs Bank in the Central Baltic Sea, shows a similar decline of 64 % in the same period (Skov *et al*. 2011).

Before the period of decline, spring migration counts on the south coast of Finland indicated pronounced 3–4 year fluctuations in winter numbers in the Baltic until a peak was reached during 1991–1993 (Hario *et al*. 2009). Fluctuations are explained by lemming cycles which strongly affected annual breeding productivity in the Arctic until 1995, when this influence ceased and numbers of migrating birds remained low (Hario *et al*. 2009). The low Long-tailed Duck densities we recorded in 1988 and 1990 may reflect the lower numbers of migrating birds in these years. Moreover, two out of three surveys took place after mid-March when densities are lower due to migration. Therefore our counts prior to 1992 probably missed times of peak densities.

There are no indications that the Baltic winter

Table 3. GAMM results for the effects of explanatory variables on Long-tailed Duck density.

Parameter	Estimate	SE	df	*t*	*F*	*p*
Coefficients						
Intercept	3.59	0.15	–	23.98	–	< 0.001
Platform, ship	0					
Platform, aircraft	–0.31	0.17	–	–1.79	–	0.078
Smooth terms						
Year	–	–	4.84	–	12.61	< 0.001
Day	–	–	2.38	–	4.44	0.011
Variance explained (R^2)	0.66	–	–	–	–	–

population has recovered from the decline since 2010, as breeding productivity was low until 2012 (Christensen 2013). Increasing densities in our study area were likely caused by ice-induced local movements. Before our surveys in 2012–2014, ice along the coasts of the Pomeranian Bay outside the study area had probably driven ducks into the ice-free centre of the Bay. In contrast, we recorded the lowest densities in 2010 and 2011 shortly after large parts of our study area had been covered by ice for several days. We expect future fluctuations in Long-tailed Duck numbers to be less marked than before the decline. Nevertheless the similarity between peak densities in 2012–2014 and those before 1994 indicates that habitat conditions in the Pomeranian Bay may still be suitable for large numbers of Long-tailed Ducks.

Trends in Long-tailed Duck densities in the Pomeranian Bay thus reflect changes in the entire winter population in the Baltic Sea until 2009. Spatial modelling results from 2007–2009, however, show higher numbers on the Northern and Southern Midsjö Banks and Słupsk Bank (Skov *et al*. 2011). Northward shifts in winter distributions have been recorded in other species wintering in the Baltic (Lehikoinen *et al.* 2013), and this process may have caused the decline in our study area to be more marked than the overall decline in the Baltic.

4.2. Survey methods

Previous studies comparing the two survey platforms did not apply corrections to the raw data from at least one platform (Briggs *et al*. 1985, Ford *et al*. 2004, Henkel *et al*. 2007). Our model shows that densities obtained with the two different platforms are comparable and available for combined analysis, when the correction procedure for aerial observations accounts for observer efficiency as well as for distance dependent detection. Without accounting for observer efficiency, aerial counts may considerably underestimate densities of Long-tailed Ducks compared with ship-based surveys. Because of diving activity and responsive behaviour of the species, ship-based surveys may also suffer from some inter-observer variability. This could not be taken into account in this study due to the high number of observers.

The basic assumption of distance sampling that all objects on the transect line are detected (Buckland *et al*. 2001, Thomas *et al*. 2010) is frequently applied without testing (Bächler & Liechti 2007). Clearly it is violated in aerial surveys where the transect line is invisible below the aircraft, and due to the high speed of the survey platform a full detection of birds (including species identification) is practically impossible for a single observer (Buckland *et al*. 2001). This is especially true when counting seaducks that are concentrated in dense flocks. Recent trials with digital techniques also suggested that visual aerial surveys underestimate seaduck abundance (Buckland *et al*. 2012). Accounting for this should become standard practice for aerial surveys of seaducks. We did not change the width of transect band A, where the vast majority of birds is detected during aerial line-transect surveys, and used this to estimate observer efficiency. Thus we could apply the corrections obtained with the improved design since 2006 also to the raw data from 2003–2004 without increasing the relative difference between platforms.

We believe that visual aerial surveys should account for sources of imperfect detection other than distance in future. Comparing corrected densities from different survey methods in the same month revealed that aerial densities were on average 30% lower than ship-based estimates, with high variation between monthly paired results. While the variation could be explained by movements between the surveys, the remaining apparent underestimation of densities by aerial counts may be due to Long-tailed Ducks frequently diving before the approaching aircraft (Pihl & Frikke 1992). Observations from only one aircraft do not allow to correct for birds unavailable for detection (Buckland *et al*. 2012). We recommend further work on this topic in order to optimise the methodological approach for monitoring seaducks, particularly by comparing simultaneous ship-based and aerial observations. This would allow estimation of the true size of a possible platform effect separately from variation between different count dates.

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Allimäärien väheneminen Pommerinlahdella kahden eri seurantamenetelmän osoittamana

Talvehtivien allien määriä seurattiin Pommerinlahdella vuosina 1988–2014 sekä laivasta että lentokoneesta tehdyillä laskennoilla. Molemmissa laskennoissa huomioitiin etäisyyden vaikutus havaitsemistodennäköisyyteen.

Lentolaskennat tehtiin kahden havainnoitsijan linjalaskenta-asetelmalla, tavalla joka mahdollisti havaitsemistodennäköisyyden arvioimisen linjan kohdalla. Koska tämä todennäköisyys oli selvästi alle 1, korjattiin se myös havainnoitsijan tehokkuudelle. Silloin molemmat laskentatavat antoivat samankaltaisia tiheyksiä, joskin lentolaskentojen tuottama ilmeinen aliarvio kaipaisi lisää ristiintarkistusta.

Molemmat tiheysarviot yhdistettiin jatkoanalyysejä varten. Saavutettuaan huipun vuosina 1992–1993, talvehtivien allien tiheys väheni 82 % vuoteen 2010 mennessä. Tämä väheneminen on osaa laajempaa vähenemistä kautta Itämeren. Ilmeinen nousu vuodesta 2010 lähtien johtunee paikallisen jäätilanteen muutoksesta ja sen aiheuttamasta liikehdinnästä. Se viittaa myös siihen, että tutkimusalueen elinympäristöt pystyvät edelleen ylläpitämään suuria allitiheyksiä.

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