DISCOVERY OF THE FIRST RECORDED LIVE POPULATION IN THE UK OF THE LAGOON SPIRE SNAIL *SEMISALSA STAGNORUM* (GMELIN, 1791) (GASTROPODA: COCHLIOPIDAE) WITH NOTES ON ITS HABITAT AND CONSERVATION

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Abstract Semisalsa stagnorum *is a "hydrobioid" snail that, until 2005, was only known in Britain from dead shells from two sites in England: a Roman and Saxon aged archaeological complex in Bath, Somerset and from modern sediments taken from a brackish lagoon on Farlington Marshes, Hampshire. In 2005 freshly dead shells were discovered in a slightly brackish lagoon on Thorney Island, West Sussex with live animals confirmed there in 2006. Studies between 2005 and 2019 confirmed the restricted distribution of the snail on the 'island' (now effectively a peninsula) and allowed data to be gathered on the snail's autecology and common associates. Sequencing of COI mtDNA confirms the population belongs to* Semisalsa *and not to any other British hydrobiid species. Comparisons are made with the ecology of similar* S. stagnorum *populations living in the Netherlands. The conservation of this Critically Endangered snail is discussed, with successional and salinity changes to its habitat being considered as the greatest threats.*

Key words Semisalsa stagnorum, Heleobia stagnorum, *brackish water, saline lagoons, sea levels, Chichester Harbour, conservation*

INTRODUCTION

Semisalsa stagnorum (Lagoon Spire Snail, Baster's Floating Snail) is a rare and declining "hydrobioid" snail, superficially similar to members of related families that occur predominantly in coastal habitats. It was first recognised and named as *Turbo stagnalis* Baster, 1765 from specimens collected in Kaaskenswater in Zierikzee (Zeeland) in the south-western Netherlands by Job Baster (Butot, 1977). Baster's species was later treated by Linnaeus as *Helix stagnalis* Linnaeus, 1767. As this name had already been used (*Helix stagnalis* Linnaeus, 1758) for the species now known as *Lymnaea stagnalis*, it was renamed by J.F. Gmelin as *Helix stagnorum* (Gmelin, 1791). For many years, *Helix stagnorum* was confused with *Turbo ventrosus* Montagu, 1803, including in British lists (e.g. Kennard & Woodward, 1926). Most older British records or museum labels of "*stagnorum*" thus relate to what is now *Ecrobia ventrosa* (Montagu, 1803). Both species were redescribed by Bank *et al.* (1979) from a neotype of *stagnorum* (from Kaaskenswater) and a lectotype of *ventrosa* (from Sandwich, Kent).

The classification of *Helix stagnorum* has changed numerous times with the species treated in various families and genera including *Hydrobia*, *Heleobia*, *Semisalsa*, *Ventrosia* and *Ecrobia* (Welter-Schultes, 2012). Most recently MolluscaBase (2020) accepted the name as *Semisalsa stagnorum* (Gmelin, 1794) in Cochliopidae. The type species of *Heleobia* Stimpson, 1865 is the South American *Paludina culminea* d'Orbigny, 1838. The name *Semisalsa* Radoman, 1974 was introduced for *S. dalmatica* Radoman, 1974 and two other Mediterranean species, and has been used as a subgenus of *Heleobia* by many authors (e.g. Glöer, 2019). Around the Mediterranean coast *S. stagnorum* is one of 14–15 very similar nominal *Semisalsa* species, most of which occur in lagoon habitats and are considered endemic to small areas (Glöer, 2019). The phylogenetic work of Kroll *et al*. (2012) suggests that most *Semisalsa* species, including *S. dalmatica* (from Croatia), *S. stagnorum* (from the Netherlands) do indeed form a group distinct from *P. culminea* and other South American species of *Heleobia*. We therefore follow Kroll *et al.* (2012) and MolluscaBase (2020) in recognising *Heleobia* and *Semisalsa* as separate genera, and treat the species in question as *Semisalsa stagnorum*. The genus name *Eupaludestrina* Mabille, 1877 (type species *Hydrobia macei* Paladilhe, 1867) may prove to have priority over *Semisalsa*, according to Kadolsky (2012). This seems likely

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if DNA data show *H. macei* belongs to the same genus as other *Semisalsa*; we cannot however resolve this issue here.

Due to uncertainty about the identification of *S. stagnorum* and similar species, the snail's distribution is unclear, but all authors recognise it as the only *Semisalsa* species in northern Europe. Kerney (1999) stated that the distribution is poorly known with the snail occurring in the Netherlands, eastern Germany, and probably southern France, with related species occurring around the Mediterranean and into Asia Minor. Glöer (2019) gave a broad distribution of Atlantic–Mediterranean – occurring along the European Atlantic coast and the whole Mediterranean coastal region including Morocco and Tunisia, and also in Iran. *Semisalsa stagnorum* is best known from sites in the Netherlands. Gittenberger *et al*. (1998) showed that before 1970 the snail was distributed at 11 sites scattered along the Dutch coast, but by 1970–1977 it had been lost from many of these and was only present at 4 sites, all clustered in the south-western province of Zeeland. More recently detailed surveys lead by H. Raad have focused upon potentially suitable *S. stagnorum* sites throughout Zeeland. In the period between 2007–2012 out of 137 sites he surveyed, 21 (15%) supported the snail (Raad, 2009, 2011, 2012 and 2013). In Britain, prior to 2005 *S. stagnorum* was only recognised from two sites (Kerney, 1999). These locations and the newly discovered site are shown in Fig. 1.

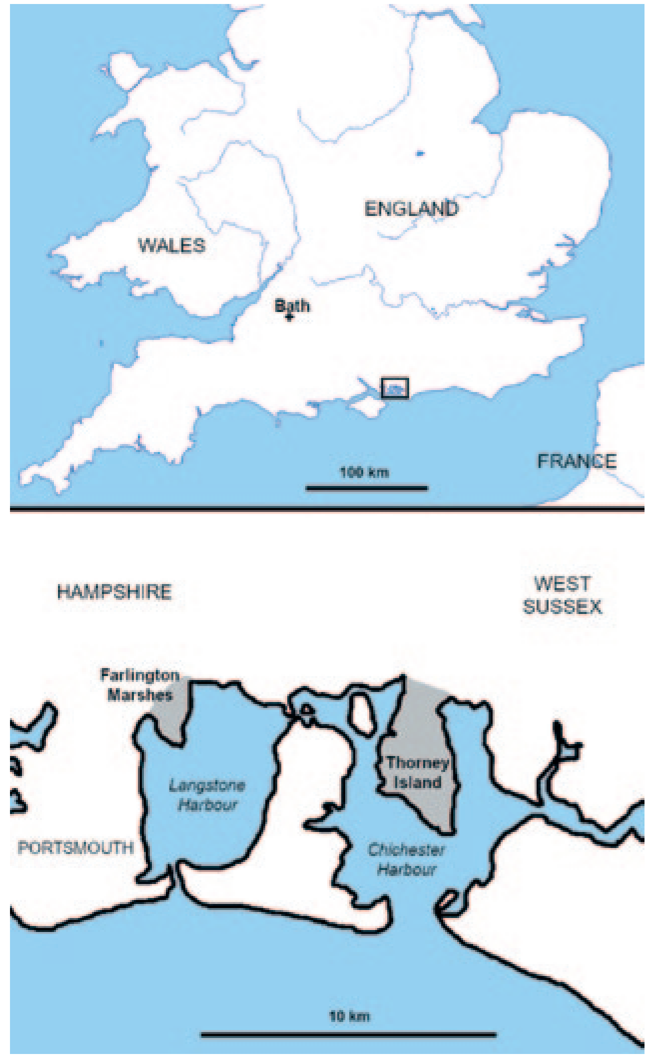

Figure 1 Map of the southern UK showing all known sites for *Semisalsa stagnorum*.

The first site was at Bath, Somerset where numerous shells, originally identified as *Potamopyrgus jenkinsi* (E.A. Smith, 1889) (= *P. antipodarum* (Gray, 1843)), were recovered from deposits associated with the Great Bath and assumed to date from Roman times (Kennard, 1941). These specimens were later reidentified as *E. ventrosa* (Bondesen & Kaiser, 1949), then later still reidentified as *S. stagnorum* (Kerney, 1999). More recently archaeological studies associated with the Southgate Redevelopment in Bath (Davies, 2010; Allen, 2012) produced numerous *S. stagnorum* specimens from a narrow band of deposits extracted from a ditch considered to be of late Saxon age (dated between approximately 900–1,066 AD – M. Allen, personal communication). The horizon containing the snails was believed to have been deposited by a spring; the associated presence of 8 terrestrial and 6 other freshwater mollusc species from a range of habitats indicated the allochthonous nature of the deposit. It is possible that the *S. stagnorum* shells were not contemporaneous with the Saxon structure and may have been washed in following the erosion of older sediments, but earlier Roman age deposits from this site did not contain *S. stagnorum* shells suggesting that the snail may indeed have being living in the Saxon period. The Roman bathing complex was started in Bath in about 60–70 AD with work continuing for the next 300 years (Anon. 2020); if the snails were living close to the Saxon ditch (dated 900–1,066) then *S. stagnorum* may have been living in Bath for a period ranging between 700–1,000 years. Although speculative, it may, of course, have been present in the area before the Roman occupation and have persisted until well after the Saxon period. As some spring waters arising from sites in Bath are slightly saline (Kellaway, 1991), it is possible that slightly brackish pools in the area may have provided suitable habitat for *S. stagnorum* populations.

The second British site, and the first recognised as supporting a recent *S. stagnorum* population was Farlington Marshes, Hampshire. This is a Hampshire and Isle of Wight Wildlife Trust reserve lying in Langstone Harbour near Portsmouth. In 1982 A. Jeram (personal communication to M.P. Kerney) found large numbers of *S. stagnorum* shells (identification confirmed by J.M. Butot at Rijksinstituut voor Natuurbeheer, Netherlands) from sediment cores extracted from a brackish lagoon at the site. The snails were estimated to have been living there for 190–200 years from about 1770 when the lagoon was created until between 1960–70 when they died out. A return visit to Farlington Marshes in September 2019 by the authors and H. Powell sampled several potential *S. stagnorum* supporting brackish lagoons on the site, but found neither live animals nor dead shells.

Here we report on a third site and the first confirmed live presence of *S. stagnorum* in the UK. This arose from surveys undertaken on Thorney Island in Chichester Harbour, West Sussex. Thorney Island (Fig. 2) is the westernmost of the three peninsulas that run into Chichester Harbour and bordered by Thorney and

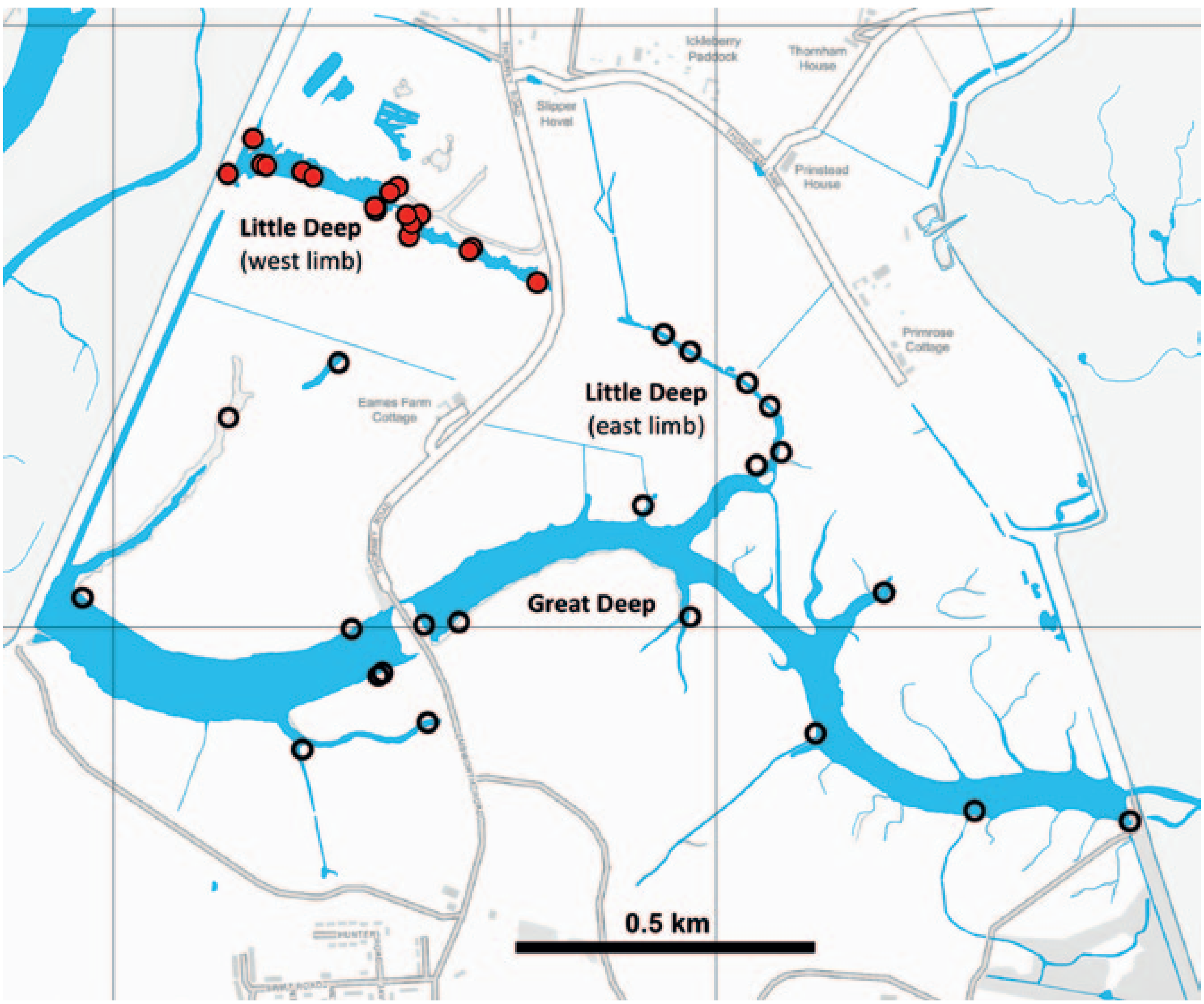

Figure 2 Map of part of Thorney Island, Chichester Harbour, West Sussex showing survey sites (2005–2019) where *Semisalsa stagnorum* was found (red circles) or not found (open circles). Map modified from Sussex Biodiversity Records Centre; contains Ordnance Survey Open Data (C) Crown Copyright.

Emsworth Channels to the east and west respectively. Thorney Island is bisected by a channel known as the Great Deep. Until about 1870 the southern half of Thorney was an island crossed by a causeway only uncovered at low tides. After that date, a sea wall was built around the island and a road constructed joining the southern half of the island with the mainland. The Little Deep was formerly a branch of the Great Deep which cut off another small island on Thorney's western margins. The eastern limb of the Little Deep still makes direct contact with the Great Deep and the salinity of its waters is directly affected by this connection. The Little Deep's western limb is now an isolated lagoon with no direct connection with either the Emsworth Channel to the west, or the eastern branch of the Little Deep, the two being separated by Thorney Road. Here a general molluscan survey in 2005 turned up large numbers of freshly dead shells in the western Little Deep (Willing, 2006). Further surveys on the island in 2006, 2007, 2009 and 2019 confirmed the live presence of the snail throughout the western section of the Little Deep lagoon, but did not find further populations of the snail in all other potentially suitable sites on the island (Willing, 2007, 2010). These surveys also gathered autecological and environmental data on the snail contributing to an understanding of its biology. *S. stagnorum* is a NERC (2006) Section 41 Species of Principal Importance in England and was assessed in the latest UK Status Review of non-marine Mollusca as Critically Endangered (Seddon *et al.,* 2014). This paper considers risks to the important Thorney Island population and possible conservation measures needed to retain it.

Methods

We here present a detailed account of the occurrence and persistence of *S. stagnorum* and its associates on Thorney Island, where the living population was discovered, over several years.

Semisalsa stagnorum surveys were undertaken in the Little and Great Deeps in 2005, 2006 and 2009 and with surveys in the Little Deep only in 2007 and 2019. Additionally, in September 2019, lagoon sites were visited at Farlington Marshes. All aquatic sites were surveyed with a broadly similar methodology. This entailed using a standard FBA-pattern extendable-handled pond net with a 0.5mm mesh as described in Murray-Bligh (1999) and supplied by EFE & GB Nets. On the Great Deep and associated channels this was used to sweep areas of water amongst submerged vegetation, and close to the bottom to skim surface sediments down to a depth of about 4–6cm either from the shore or by shallow wading. Between 2005–2009 locations on the Little Deep were accessed by wading through the extensive marginal *Phragmites* reedbeds. In 2019, in order to sample central areas of the lagoon (otherwise inaccessible from the margins), these were surveyed from a two-man inflatable craft. Each site was sampled for about 10 minutes to recover a representative sample. To allow approximate quantitative comparisons to be made between sites, ten 2m sweeps of bottom sediments were undertaken. On the Little Deep when sampling from the reedbed-open water interface, net sweeps were equally divided between the *Phragmites* margin and open water sediments lying between 1–3m from the edge. During the boat survey in 2019 netting was undertaken directly from the boat. To recover all small species and juveniles, 'bulk samples' of aquatic vegetation and channel sediments were removed from each site for later laboratory processing. This involved sieve-tier washing of vegetation and sediments to retain all molluscan remains > 0.5mm. Residues were examined on gridded white trays and smaller samples inspected microscopically using a x5–x56 binocular microscope. Samples of Crustacea and macrophytes collected during sampling were retained for independent expert identification.

At each sampling site, brief habitat descriptions were gathered, digital site images obtained and site locations recoded with a Garmin E-Trex Summit GPS device. Salinity measurements were undertaken at selected locations in the Little Deep and Great Deep in 2006 and 2009, on the former occasion using a Hanna Hi 9835 auto ranging meter and the latter with a salinity meter supplied and calibrated on the day of use by the Environment Agency (Chichester). Water samples taken from the Little Deep and from two lagoons on Farlington Marshes in September 2019 were taken in sealed containers for testing (on the day following collection) at the National Museum of Wales, Cardiff with a density and pH meter.

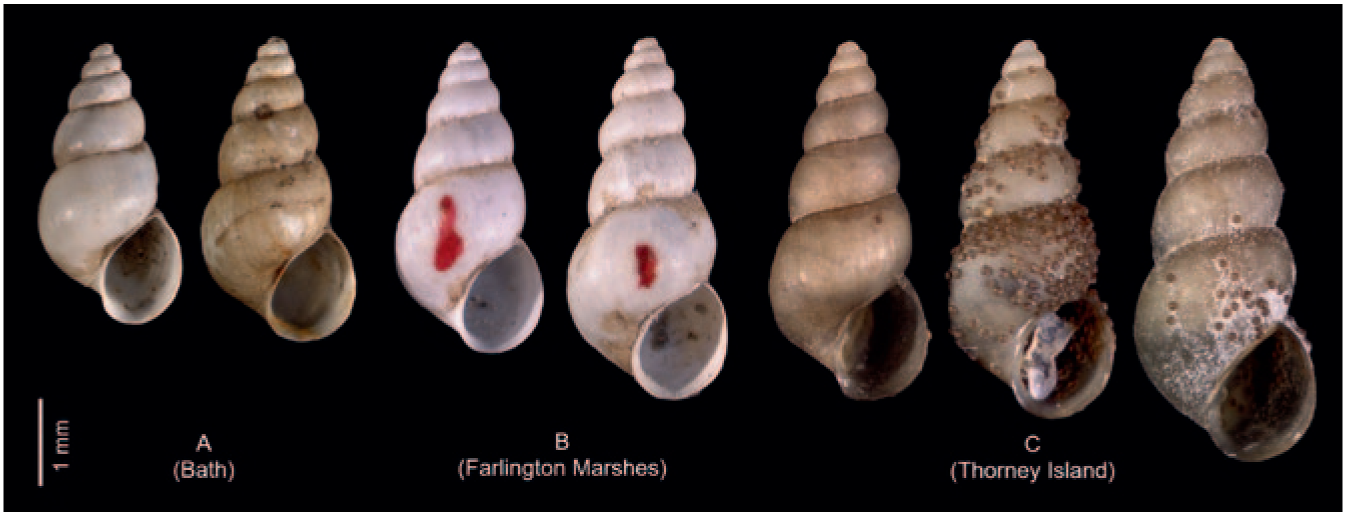

Figure 3 Shells of *Semisalsa stagnorum* from the three known British sites. A, Bath (collection of M. E. Allen); B, Farlington Marshes (University Museum of Zoology, Cambridge); C, Thorney Island (National Museum of Wales, Cardiff, NMW.Z.2015.021.00001).

To confirm the identification of the new Thorney *S. stagnorum* population shells were compared with dead specimens from the other British sites at Farlington and Bath (Fig. 3) as well as the examination of museum material from the Netherlands and Greece. Material from the 2005 and 2006 surveys was confirmed as *S. stagnorum* from specimens and or photographic images by a variety of experts familiar with the species including Roy Anderson, Ruud Bank, Barry Colville, David Holyoak, Michael Kerney, Tom Meijer and Richard Preece. DNA was extracted from head-foot tissue from two 2019 Thorney Island specimens, and the COI mtDNA "barcoding" fragment amplified using standard primers and conditions as described in Rowson *et al*. (2014). Two sequences 620 bp in length (GenBank accession numbers MT913154-5) were obtained and compared to sequences on GenBank by BLASTn search. Both closely matched (BLASTn identity 97.9–98.6%, coverage 98–99%) COI sequences of *S. stagnorum* and other *Semisalsa* species from the studies by Kroll *et al*. (2012) and Hershler *et al*. (1999). The sequences were highly dissimilar to others (unpublished data) from British *Ecrobia ventrosa* (Montagu, 1803), *Peringia ulvae* (Pennant, 1777), and *Potamopyrgus antipodarum* (Gray, 1840). We therefore conclude that the Thorney Island population belongs to *S. stagnorum*, and is conspecific with the empty shells from Bath and Farlington Marshes.

Results

Surveys were undertaken on Thorney Island on 5 separate periods between 2005 and 2019. *Semisalsa stagnorum* was repeatedly found in the western limb of Little Deep, always in association with *Potamopyrgus antipodarum*, but never in either the Little Deep eastern limb or the Great Deep, both of which were inhabited by species characteristic of more saline waters (Figure 2). A summary of all molluscan results obtained from the Little Deep (western and eastern limbs) and the Great Deep from the surveys between 2005–2019 is given in Table 1.

The 2005 survey found the first *S. stagnorum* in the Little Deep (western limb) as freshly dead shells at both sample sites (Willing, 2006). These were found along with dead *Potamopyrgus antipodarum*, a species of low salinity habitats. The two samples taken from the Great Deep instead produced live *Peringia ulvae* and, in one side channel *Ecrobia ventrosa*, two species typical of more saline habitats.

In 2006, *S. stagnorum* were found living at 5 sites located at different locations in the western Little Deep, and additional samples from the Great Deep again produced *Peringia ulvae* and brackish-water bivalves further confirming its more saline conditions (Willing, 2007). Sampling in the eastern limb of the Little Deep, which directly connects with the saline waters of the Great Deep produced no evidence of *S. stagnorum*.

Table 1 Combined Molluscan Results 2005–2019

Area and species	OS Grid	Abundance	Date	Reference
Semisalsa stagnorum				
Little Deep (west limb)	SU 75473 04732	2 dead	Autumn 2005	Willing 2006
Little Deep (west limb)	SU 75247 04769	24 dead	Autumn 2005	Willing 2006
Little Deep (west limb)	SU 75596 04630	10 live, 17 dead	Autumn 2006	Willing 2007
Little Deep (west limb)	SU 75510 04686	6 live, 23 dead	Autumn 2006	Willing 2007
Little Deep (west limb)	SU 75492 04650	9 live, 8 dead	Autumn 2006	Willing 2007
Little Deep (west limb)	SU 75436 04693	23 live, 14 dead	Autumn 2006	Willing 2007
Little Deep (west limb)	SU 75314 04757	8 dead	Autumn 2006	Willing 2007
Little Deep (west limb)	SU 75496 04670	35 live, 8 dead	Autumn 2007	Willing (unpublished)
Little Deep (west limb)	SU 75436 04698	18 live, 31 dead	Autumn 2007	Willing (unpublished)
Little Deep (west limb)	SU 75705 04573	26 live, 5 dead	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75592 04626	5 live, 1 dead	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75488 04685	89 live, 2 dead	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75434 04698	10 live, 8 dead	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75232 04812	82 live, 3 dead	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75190 04754	87 live, 7 dead	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75460 04723	28 live, 17 dead in total,	Autumn 2019	Present study
Little Deep (west limb)	SU 75332 04749	present at all three 2019	Autumn 2019	Present study
Little Deep (west limb)	SU 75254 04767	sites	Autumn 2019	Present study
Potamopyrgus antipodarum				
Little Deep, (west limb)	SU 75473 04732	24 dead	Autumn 2005	Willing 2006
Little Deep, (west limb)	SU 75247 04769	30+ dead	Autumn 2005	Willing 2006
Little Deep, (west limb)	SU 75510 04686	frequent live	Autumn 2006	Willing 2007
Little Deep, (west limb)	SU 75596 04630	frequent live	Autumn 2006	Willing 2007
Little Deep, (west limb)	SU 75492 04650	frequent live	Autumn 2006	Willing 2007
Little Deep, (west limb)	SU 75436 04693	frequent live	Autumn 2006	Willing 2007
Little Deep, (west limb)	SU 75314 04757	frequent live	Autumn 2006	Willing 2007
Little Deep (east limb)	SU 75959 04458	occasional dead	Autumn 2006	Willing 2007
Little Deep (east limb)	SU 76110 04291	2 live, occasional dead	Autumn 2006	Willing 2007
Little Deep (west limb)	SU 75496 04670	frequent live	Autumn 2007	Willing (unpublished)
Little Deep (west limb)	SU 75436 04698	frequent live	Autumn 2007	Willing (unpublished)
Little Deep (west limb)	SU 75705 04573	141 live	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75592 04626	113 live	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75488 04685	67 live	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75434 04698	321 live	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75232 04812	1020 live	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75190 04754	877 live	Autumn 2009	Willing 2010
Little Deep (west limb)	SU 75460 04723	Occasional live and dead,	Autumn 2019	Present study
Little Deep (west limb)	SU 75332 04749	present at all three sites	Autumn 2019	Present study
Little Deep (west limb)	SU 75254 04767		Autumn 2019	Present study
Ecrobia ventrosa				
Little Deep, (west limb)	SU 75247 04769	1 dead (old, bleached shell)	Autumn 2005	Willing 2006
Great Deep, side channel	SU 77538 03865	500+ live	Autumn 2005	Willing 2006
Little Deep (east limb)	SU 76091 04367	few (old, bleached shell)	Autumn 2006	Willing 2007
Little Deep (east limb)	SU 7606904269	few (old, bleached shell)	Autumn 2006	Willing 2007
Great Deep, side channel	SU 75500 03846	500+ live	Autumn 2009	Willing 2010
Peringia ulvae				
Great Deep, main channel	SU 77058 00765	frequent live	Autumn 2005	Willing 2006
Little Deep (east limb)	SU 76110 04291	frequent live	Autumn 2006	Willing 2007
Little Deep (east limb)	SU 76069 04269	frequent live	Autumn 2006	Willing 2007
Great Deep, main channel	SU 75880 04202	frequent live	Autumn 2006	Willing 2007

Table 1 (*Continued*)

Area and species	OS Grid	Abundance	Date	Reference
Great Deep, main channel	SU 75959 04016	6 live	Autumn 2009	Willing 2010
Great Deep, main channel	SU 76281 04057	34 live & dead	Autumn 2009	Willing 2010
Gyraulus crista				
Little Deep (west limb)	SU 75190 04754	1 live	Autumn 2009	Willing 2010
Cerastoderma glaucum				
Great Deep, main channel	SU 75880 04202	frequent live and dead	Autumn 2006	Willing 2007
Abra tenuis				
Great Deep, main channel	SU 75880 04202	abundant live and dead	Autumn 2006	Willing 2007

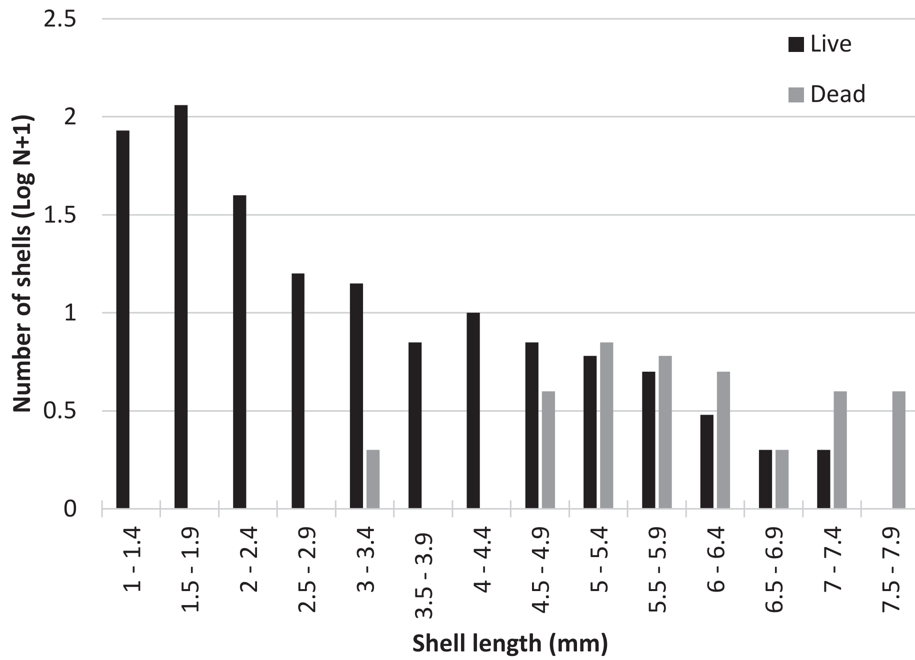

Figure 4 Size frequency distribution of *Semisalsa stagnorum* from the Little Deep (west limb) collected September 2009.

Two Little Deep sites revisited in Autumn 2007 further confirmed the presence of live *S. stagnorum* on the southern margins of the Little Deep.

The Autumn 2009 Chichester Harbour Conservancy project (Willing, 2010) surveyed all habitats on Thorney Island potentially suitable for *Semisalsa stagnorum*. Sampling points evenly distributed along the western Little Deep confirmed the presence of large numbers of live snails at most locations where it was found together with abundant *Potamopyrygus antipodarum*. A single specimen of the freshwater snail *Gyraulus crista* (Linnaeus, 1758) was also recorded from a single site the Little Deep (western limb). Sampling collected a total of 302 live *S. stagnorum* (plus 26 dead shells) the great majority being juvenile snails (Fig. 4). Measurement of the live cohort revealed a small proportion of individuals (10, under 1%) exceeding the previous widely cited maximum length for the species of 6.3mm (eg. Gittenberger *et al.*, 1998; Glöer, 2019). The largest specimens reached 7.2mm (live) and 7.8mm (dead shell).

The use of a boat on the survey day in September 2019 confirmed the continued presence of abundant live *S. stagnorum* in the western Little Deep, not only living in marginal areas immediately adjacent to the *Phragmites* fringed margins, but also amongst *Potamogeton pectinatus* and bottom sediments in central open-water areas of the lagoon. The samples, which were

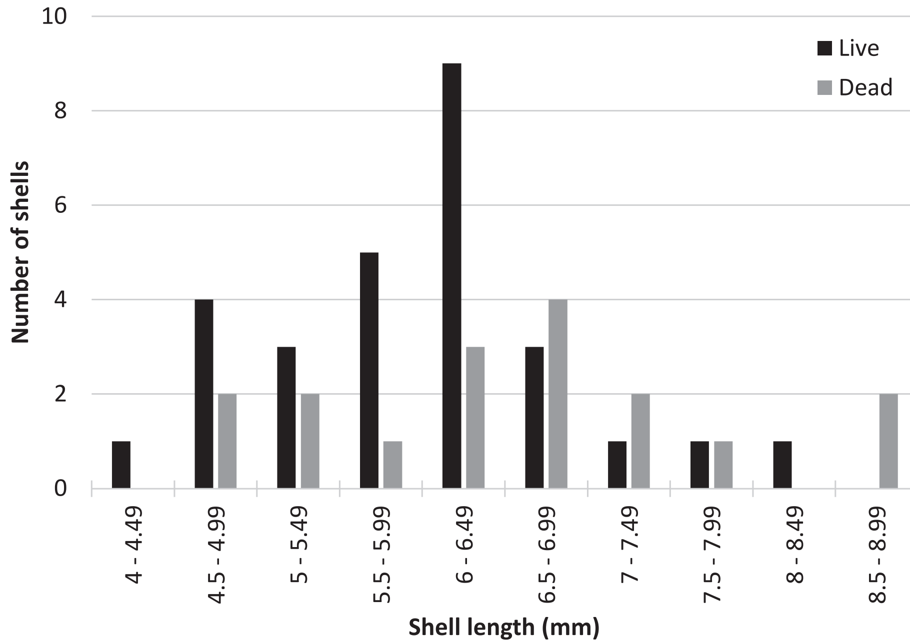

Figure 5 Size frequency distribution of *Semisalsa stagnorum* from the Little Deep (west limb) collected September 2019.

mainly comprised of adult snails, also produced further large individuals with 8 live specimens (29%) and 10 dead shells (59%) exceeding the previously widely cited maximum shell length of 6.3mm. Maximum shell lengths were 8.2 and 8.95mm respectively (Fig. 5).

Water salinity measurements were taken at various locations in 2006, 2009 and 2019 and additionally data was obtained from a Chichester Harbour Conservancy internal report (Anon., 1988) of measurements taken in 1988 (Table 2). Examination of the results show a remarkably small range of low salinity (mesohaline) water in the Little Deep ranging between 3.2–5.47 ‰ over a 31-year period. By contrast, salinity readings for the Great Deep range between 27.2–34.5 ‰ salinities close to, or even exceeding typical sea water salinity values in the adjacent Chichester Harbour.

Farlington Marshes (Langstone Harbour) were also briefly visited in September 2019 and salinity readings taken from the main western lagoon (SU 68075 03912) of 9.3 ‰ and an adjacent ditch (SU 68075 03790) of 46.3 ‰. *Peringia ulvae* was found in the main lagoon, and *Ecrobia ventrosa* in the ditch. The presence of a typical saltmarsh flora (*Salicornia* spp., *Aster tripolium*) around the margins of the main lagoon (the site that may have supported *H. stagnorum* until the 1970s) suggests much more saline conditions than exist in the Little Deep. A rise in salinity in the main Farlington lagoon may therefore have caused of the loss of the snail from the site, while the ditches, if hypersaline, may never have been suitable. The pH of all the water bodies tested in 2019, including the Little Deep, was between 7 and 8.

The identification of animals and plants found during sediment and sample collecting reveals the most frequent organisms found living with *S. stagnorum*. In the Little Deep *S. stagnorum* lives with the snail *Potamopyrgus antipodarum* and a similar community found when sampling in 2005, 2006, 2007, 2009 and 2019. Only one macrophyte, Fennel Pondweed *Potamogeton pectinatus* has been recorded in the lagoon's clear waters. This species is frequent in brackish and eutrophic waters in a wide range of habitats (Preston, 1995). The lagoon supports a variety of Crustacea including the decapod *Palaemon varians*, Leach, 1814) the two amphipods *Gammarus zaddachi* Sexton, 1912 and *G. salinus* (Spooner, 1947) and the isopod *Lekanesphaera hookeri* (Leach, 1814). All these species are found a variety of brackish habitats including waters that are only slightly brackish (T. Worsfold, personal communication). The fine calcareous sediments of the lagoon support an extremely rich assemblage of Ostracoda. A sediment sample examined by John Whittaker (formerly of Dept. of Earth Sciences, The Natural

Table 2 Salinity measurements from the western Little Deep and Great Deep 1988–2019

Report & year	Salinity ‰	
	Western Little Deep (multiple listed appear east > west)	Great Deep (multiple listed appear west > east)
1988 (Chichester Harbour Conservancy 1988)	3.64 (SU 75214 04783)	34.5 (SU 74924 04054) 32.7 (SU 75605 04116) 22.08 (SU 76613 03707)
2006 (August / October) (Willing 2007)	5.39 (SU 75596 04630) 5.35 (SU 75492 04650) 5.49 (SU 75436 04693) 5.47 (SU 75314 04757)	27.2 (SU 76015 04252)
2009 (September / October) (Willing 2010)	5.46 (SU 75705 04573) 5.47 (SU 75592 04626) 5.43 (SU 75488 04685) 5.46 (SU 75434 04698) 5.44 (SU 75232 04812) 5.44 (SU 75190 04754)	33.52 (SU 75441 03918) 32.9 (SU 75500 03846) 33.2 (SU 75574 04008)
2019 (September) (present study)	3.2 (SU 75460 04723) 3.2 (SU 75332 04749) 3.3 (SU 75254 04767)	X

History Museum) revealed 6 species; live *Cyprideis torosa* (Jones, 1850) and *Candonocypris novaezelandiae* (Baird, 1843) together with dead *Candona angulata* G.W.Muller, 1900, *Heterocypris salina* (Brady, 1868), *Herpetocypris reptans* (Baird, 1835) and *Sarscypridopsis aculeata* (Costa, 1847). As the dead species are represented by adults and juveniles it can be assumed that all live in the lagoon at some time during the year. *C. torosa* is a common brackish water species living in all manner of estuarine, lagoonal and coastal environments in salinities from near freshwater to hypersaline conditions. The other species are all "freshwater ostracods", but more correctly termed "non-marine", as they can tolerate low salinities in coastal environments. The discovery of *C. novaezelandiae* is of interest. This species was until recently considered as endemic to Australia and New Zealand but has also recorded from South Africa. Scarf *et al.* (2014) now report the species as present in both North Africa and northern Europe including this Thorney Island find as the first for the species from Britain. They suggest that these newly discovered populations may have been introduced by migratory water birds; if this is the case then the Thorney populations may have been introduced directly from North Africa or northern Europe. The Little Deep certainly attracts a wide range of migratory birds including gulls, terns, and ducks as well as scarce breeders such as Bearded Reedling *Panurus biarmicus* (Linnaeus, 1758) (personal observations).

Discussion

Habitat

Coastal lagoons are often part of a complex mosaic or network of water bodies, between which salinity varies and fluctuates considerably. In the western limb of the Thorney Island Little Deep *S. stagnorum* lives in a specific non-tidal habitat consisting of clean, clear, low-salinity water displaying no signs of eutrophication. There is no obvious presence of filamentous algal mats (either floating or sediment covering 'blankets') or black anoxic sediments. Salinity data obtained from the lagoon over the 31 year period between 1988–2019 (Table 2) is remarkably consistent with values over the period ranging between 3.2–5.49 ‰ and suggests that conditions there have changed little over that period

Figure 6 Habitat of living *Semisalsa stagnorum* at the Little Deep, Thorney Island (looking east from the sea wall, August 2007).

and probably longer. Associated biota is also consistent with only slightly brackish conditions. The lagoon is surrounded by a mostly wide margin of Common Reed *Phragmites australis* (Fig. 6), but lacks halophytic plants such as *Salicornia* spp., *Atriplex portulacoides*, *Plantago maritima*, and *Aster tripolium,* common elsewhere in upper saltmarsh and bordering more saline lagoons on Thorney Island such as the Great Deep. The only macrophyte recorded in the Little Deep throughout the survey period is *Potamogeton pectinatus,* a widespread species tolerant of brackish conditions. In the Netherlands *S. stagnorum* is described as occupying waters in the salinity range 2.6–13.2 ‰ (Bank *et al.*, 1979) a salinity at the lower end of the 'mesohaline' range 3.3–18.1 ‰ of Gittenberger *et al.* (1998) and so providing clear parallels with conditions in the Little Deep. The only associated mollusc in the Little Deep has been *Potamopyrygus antipodarum,* although a few dead bleached *Ecrobia ventrosa* collected from sediments in 2005 suggest the former presence of this species maybe from when waters were more saline. Recent *S. stagnorum* surveys in the southern Dutch province of Zeeland have located 21 populations of the snail (from a total of 137 sites visited). Of these 14 (67%) were in association with *Potamopyrygus antipodarum*, 20 (95%) with *Ecrobia ventrosa* and 13 (62%) with both of these species (Raad, 2009, 2011, 2012, 2013). In these studies, Raad suggested that these three hydrobioids typically display a range of salinity tolerances with *P. antipodarum* found in the least saline conditions, *S. stagnorum* in slightly higher salinities and *E. ventrosa* able to live in the most saline conditions. This also seems to be the case in England, with *E. ventrosa* living in a channel directly linked to the Great Deep, both of which have salinity levels close to 33‰.

Shell form & life cycle

Although superficially like other hydrobioids, the pale shells, relatively rounded aperture, barely complete peristome and large size of *S. stagnorum* are distinctive. Literature sources provide a wide variation of suggested typical dimensions of *S. stagnorum* shells (presumably only adult sizes are given). For shell length these range from 3–4mm (Welter-Schultes, 2012), 3.5–5mm (Kerney, 1999) or 6.3mm (Bank *et al.*, 1979; Gittenberger *et al.;* 1998, Glöer, 2002, 2019). The key to Palaearctic *Semisalsa* species by Glöer (2019) separates the two species that exceed 6mm in length from all the others. These are *S. stagnorum*, and *S. canariensis* (Mousson, 1872) which is considered endemic to the Canary Islands. The maximum length of *S. stagnorum* shells from the Little Deep considerably exceeds 6.3mm, with several individuals being over 8mm long. Nevertheless, many of the Little Deep snails, which are presumably adult, are identical in size and shape to the *S. stagnorum* shells illustrated by the other authors. Shell width estimates also vary; 1.8–2.0mm (Welter-Schultes, 2012) to 2.9mm (Bank *et al.*, 1979; Gittenberger *et al.*, 1998; Glöer, 2002, 2019). The 2019 Little Deep sample also included 8 shells (4 live and 4 dead) exceeding this width with a maximum of 3.5mm.

The 2009 sampling collected relatively few live adults (3.0–7.9mm long), but numerous juvenile snails (1–2.9mm long). In total 42 live adults were recovered compared to 255 juveniles, an approximate 1:6 ratio. Amongst a further 26 dead specimens, 5 or 6 were found which contained partly decomposed animals within their shells indicating recent death. These observations may suggest that *S. stagnorum* has an annual lifecycle with breeding occurring at some point in the autumn followed by adult mortality. Further population studies of the snail with regular sampling undertaken over several years might allow this hypothesis to be tested.

Animal

S. stagnorum found in the Little Deep had translucent tentacles containing randomly distributed,

Figure 7 Live adult *Semisalsa stagnorum*, Little Deep, Thorney Island. Photo by Paul Sterry.

variably sized, white granules the extent of which varied between individuals; a few tentacles were largely devoid of them (Figs 7–9). In their *S. stagnorum* description Bank & Butot (1984) offered a very different description describing tentacles lined on both sides with black pigment, with the lower parts of the tips as unpigmented and with occasional presence of yellow granules near the tentacle bases. By contrast no black bands were seen in any of the animals examined from the Little Deep. Gittenberger *et al.* (1998) although featuring the head illustration from Bank and Butot's earlier work, nevertheless, provide a slightly different tentacle description more closely matching that seen in the Thorney Island specimens. They described the tentacles as translucent with some internal, irregularly shaped white grains and sometimes a surface black haze. The snout of the Thorney Island specimens was typically lightly pigmented including a central dull orange-red triangular shaped, more heavily pigmented zone with a blunt apex terminating before the front edge of the proboscis. Running across the heads were also between 14–20 very narrow bands. Thus, in a revision to his earlier *S. stagnorum* head description, R. Bank (personal communication) states , "it should be black stripes on the snout running longitudinally

Figure 8 Head of live adult *Semisalsa stagnorum*, Little Deep, Thorney Island. Photo by Paul Sterry.

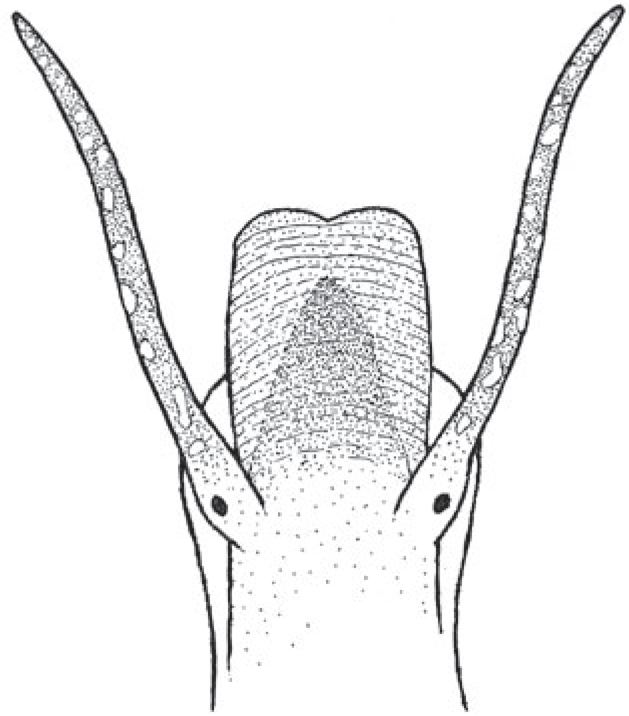

Figure 9 Drawing of head of live adult *Semisalsa stagnorum*, Little Deep, Thorney Island.

from side to side not monochromatic black as presented in the drawing*" (*as shown in the earlier snout diagram of Bank & Butot 1984). Confusingly an earlier paper (Jansson & Vogel, 1965) displays yet another *S. stagnorum* head pattern displaying colourless tentacles and a snout bordered by dark pigmented bands and with a clear unmarked central area between. The variability of the head and tentacle patterns between populations of this species may therefore need reassessment; it is possible that some misidentified material might have been used by Dutch workers.

About 50 adult *S. stagnorum* collected during the 2007 and 2009 surveys were microscopically examined when actively crawling in a water-filled container and no individuals were seen with a penis. It is not known if the Little Deep population consists solely of parthenogenetically reproducing females or if males occur in very low numbers, the examined sample being too small to detect any. Bank & Butot (1984) noted the remarkable occurrence of only one male for every 50 females, and Giusti *et al.*, (1995) noted that many Mediterranean *S. stagnorum* populations, including those from Malta, are solely female. The absence of data from male genitalia makes the DNA sequences particularly important in confirming the Thorney Island population as belonging to the genus *Semisalsa* and to *S. stagnorum*. Although many of the endemic *Semisalsa* species described from southern Europe are yet to be studied phylogenetically, all authors are consistent in recognising only *S. stagnorum*, described from the Netherlands, in northern Europe.

Conservation

The present study demonstrates that, despite reports of its extinction in Britain in the 1960s–1970s (Kerney, 1999; Glöer, 2019), *S. stagnorum* survives in at least one small water body in England. However, it also appears that its other two British sites have indeed been lost. Survey work since 2005 has demonstrated the continued presence of *S. stagnorum* in the Little Deep including the most recent 2019 visit which found large numbers of the snail and no apparent deterioration in water quality. The Little Deep benefits from being protected by lying within the Chichester Harbour AONB and the Chichester Harbour SSSI, Chichester and Langstone Harbour SPA and Solent Maritime SAC. To conserve the *S. stagnorum* population potential risks to the site need to be identified and steps taken to reduce or eliminate them. This study demonstrates that

Figure 10 Aerial view of the Little Deep (western limb), Thorney Island, showing *Phragmites* encroachment into the water body.

in the Little Deep *S. stagnorum* lives in very low salinity water which has remained remarkably stable for at least 30 years; it is therefore important to prevent major salinity changes. As previously discussed, it is believed that the loss of *S. stagnorum* from the main lagoon on Farlington Marshes in Langstone Harbour may have been due to an increase in salinity. Recent studies in the Netherlands also confirms the requirement for low salinity non-tidal conditions for *S. stagnorum* populations. The sources of freshwater and salinity into the western Little Deep are unknown. The former maybe from spring input or surface drainage from higher ground to the north. Saline input may result from seepage through the sea wall to the west and/or (as in several of the low-salinity Dutch lagoons) from leaching of underlying marine sediments. Several environmental changes threaten the lagoon's sensitive ecology including salinity change, loss of open water due to successional changes and eutrophication. Studies in the Netherland (Raad, 2009, 2011, 2012 and 2013) have linked the loss of several *S. stagnorum* populations to both the increase and decrease of salinity. Salinity increase in the Little Deep could occur as a result of several factors including (1) salt water inflow over the sea wall something possible if high spring tides coincided with a southerly storm and (2) seawater seepage through a damaged sea wall or faulty one-way drainage sluices. A decrease in salinity due to an increased freshwater inflow seems less likely. The gradual loss of open water areas due to the inward encroachment of marginal *Phragmites australis* reedbeds (Fig. 6) has been observed since the start of studies in 2005 especially at the eastern end of the site. In several places reed beds now extend across the lagoon (Fig. 10) creating a series of now separated pools. Reedbed encroachment needs to be monitored (possibly assisted by drone aerial observations) with periodic reed cutting and removal to retain the lagoon's open waters. Throughout the period of study Little Deep waters have remained clear with no signs of eutrophication. Fertilizer applications and increased cattle stock numbers risk nutrient enrichment and a subsequent algal bloom and associated anoxic conditions leading to a fall in dissolved oxygen. Management of the lagoon and adjacent land by Chichester Harbour Conservancy should allow site management to maintain the Little Deep so that it continues to support the critically endangered *S. stagnalis* population living there.

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