Dear members of GUPACA,

I have put together brief synopsis (based on ground-level data, photography, and best professional judgment) on spatial and temporal patterns of plant growth in Gull Pond. Homeowners around Gull Pond have reported an increase in the growth of aquatic plants and algae over the last few decades as is described below (reprinted from the GUPACA website):

> *"The rapid rate of plant growth has been most apparent to us. Many of us in GUPACA remember when Gull Pond had a nearly unblemished sand bottom. These are not childhood reminiscences from the prospective of old age: these changes have been occurring over the last 20 years at an increasing rate."*

This document is an attempt to synthesize existing information and offer some possible explanations for what may be going on in this pond. While some quantitative ground-level data is available, much of the analysis is based upon high altitude georectified aerial imagery as well as low-level oblique angle images. I have focused a great deal on the northeastern (NE) shoreline of the pond, since that's where many of the homeowners have witnessed the changes.

First, I will provide an explanation of how I've interpreted the aerial photography. There are three main components of the littoral zones (littoral zones are the near shore waters that are inhabited by aquatic macrophytes, algae, and mosses) of kettle ponds that produce a dark signature that contrasts with bare sand (light or white color). They are:

- Submerged, emergent, and floating macrophytes – these are aquatic plants (rushes, sedges, forbs, water lilies, etc.) that may be completely submerged, floating on the surface, or extending above the surface (depending on water level)
- Periphyton – algae (commonly filamentous green types in these ponds) that may be attached to the bottom or to aquatic macrophytes
- Aquatic mosses – submerged mosses that cover the bottom including *Drapanocladus* and *Fontinalis* species
- Organic matter – deciduous leaves and pine needles, woody debris, plant matter from previous year's growth (minor component)

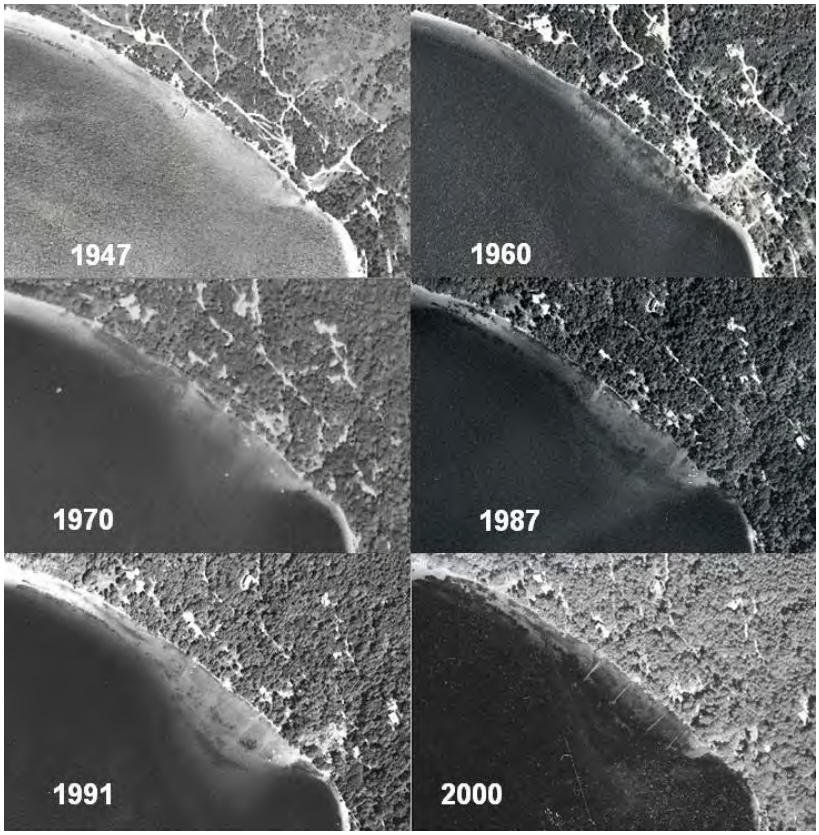
Dark signatures within the littoral zone of kettle ponds indicate the presence of one or all of the above components, although it is predominantly macrophytes, periphyton, and mosses that make up the signatures visible in aerial photographs (these components are what dominate in the ponds now). Hereafter I have referred to this signature as "ground cover". These contrast sharply with areas of bare sand, which give a bright white signature and are obvious around areas of high disturbance (e.g., public "beaches").

Above: emergent macrophytes (left), submerged periphyton (middle), and organic matter (right) – all of which produce a dark signature in aerial photography that contrasts with bare sand.

SPATIAL AND TEMPORAL VEGETATION TYPES AND PATTERNS IN AERIAL PHOTOGRAPHY AND ON THE GROUND TODAY – WHAT DO THEY TELL US?

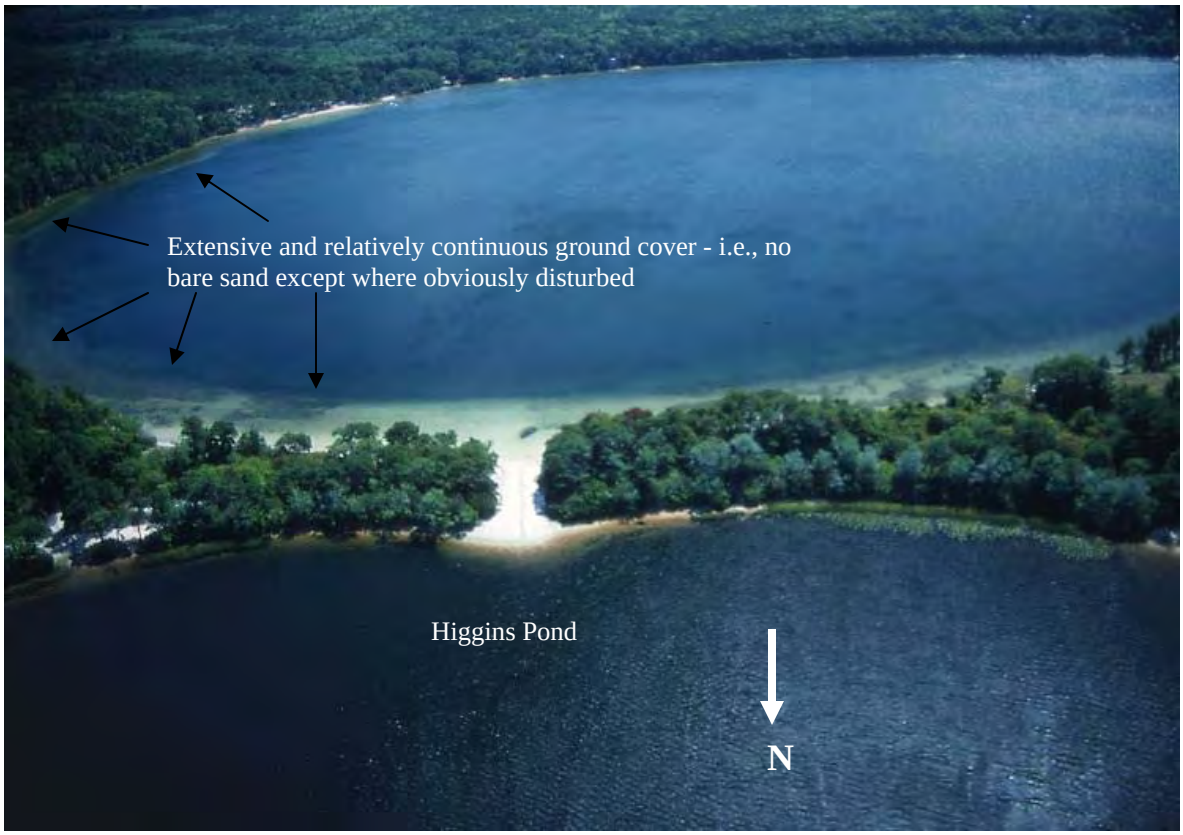
Changes along the NE shoreline over time

Over the last 60 years, there has been considerable variability in the signature of ground cover along the northeast shoreline of Gull Pond. For example, there is an apparent increase in cover from 1947 to 1960, then a decrease from 1960 to 1991 (corresponding with an increase in bare sand), and then an increase again from 1991 to 2000. Unfortunately, there is no aerial photography available from the past few years to compare with 2000. The latest photo set from MassGIS was taken in April 2005 but the quality, color, and water levels at the time makes it difficult to discern aquatic vegetation in ponds.



Above: aerial photographs of the NE shoreline of Gull Pond from 1947-2000. All were shot in September-November with the exception of 1960, which was shot in April.

Despite the apparent smaller extent of cover in 1987 compared to 2000 in high altitude photographs, low-level photos shot in 1988 show an almost complete lack of bare sand bottom along this part of the shoreline. Only where human traffic has discouraged plant and periphyton development (e.g., in and around the sluiceway and the "beach" area along the southeast part of the shoreline) can the bright white color of sand be seen.

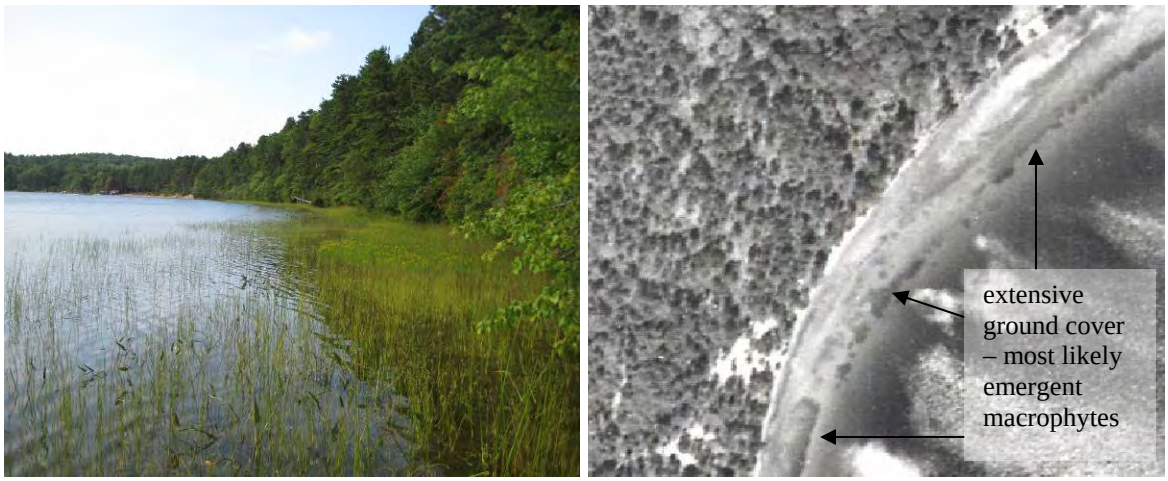


Above – Aerial photo showing relatively unbroken coverage of macrophyte/periphyton communities along the NE shoreline of Gull Pond in 1988 (20 years ago).

Above – Aerial photo showing coverage of macrophyte/periphyton communities along the NE and SW shoreline of Gull Pond in the early 1990s (exact date of photo unknown but photo was taken prior to 1995). Bare sand areas are mostly limited to the sluiceway, the town beach, and the pathways of individual homeowners.

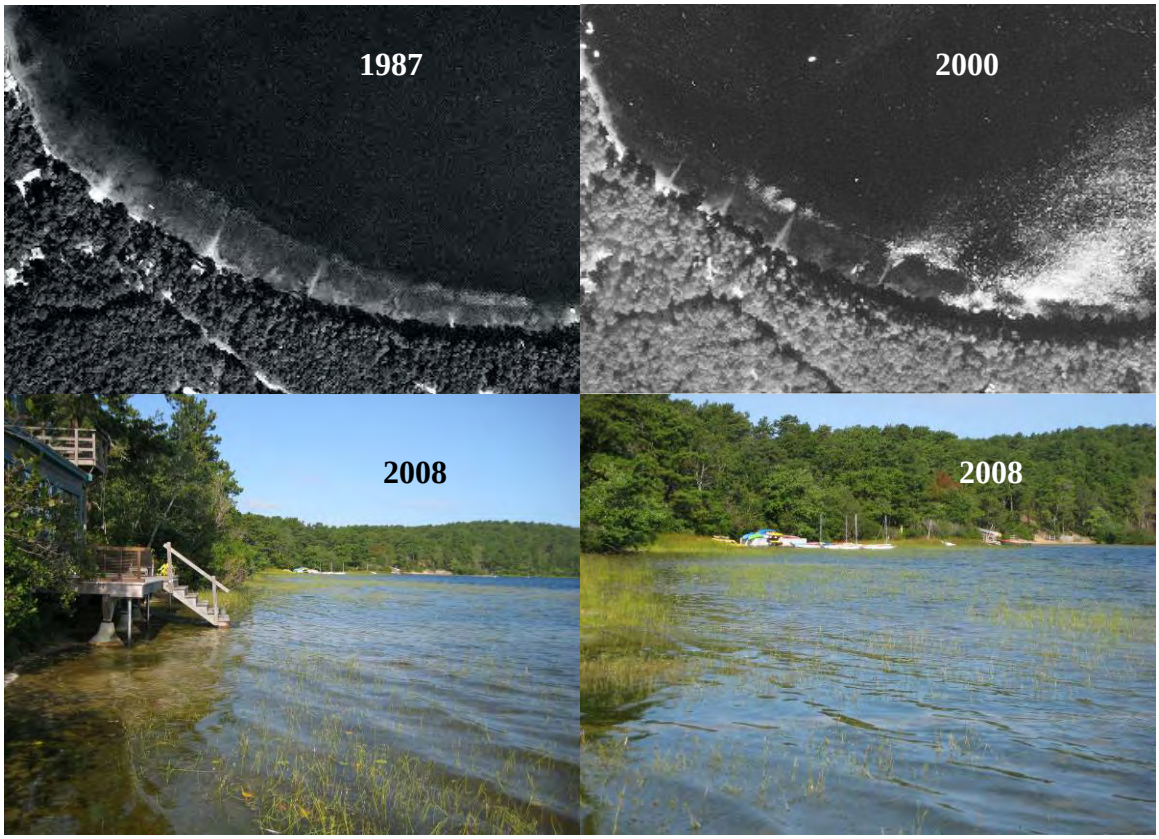
Changes in others areas of Gull Pond - Areas of dense, littoral zone vegetation/periphyton can also be found along the northwest side of Gull Pond where there is comparatively little human foot traffic in the littoral zone and no disturbance to the upland that would cause the erosion and deposition of sand into the pond. This suggests that nutrient point sources from houses along the NE shoreline are probably not the cause of excessive vegetation growth in the littoral zone there since it grows equally well in places quite distant from any houses.

In addition, ground cover along the NW shoreline appears to be as abundant in 1947 as it is now (see figure below). It is difficult to conclude that any significant changes in the extent of ground cover (macrophytes, algae, mosses) have occurred since 1947. This is also true for most of the southwest shoreline. The bare spots that are visible in these photos are clearly associated with human foot traffic (you can see the obvious paths out to deeper water) and sand plumes caused by erosion from un-vegetated or sparsely vegetated upland banks. Simply put, the kinds of temporal changes shown previously along the NE shoreline do not seem to have occurred in other areas of Gull pond.

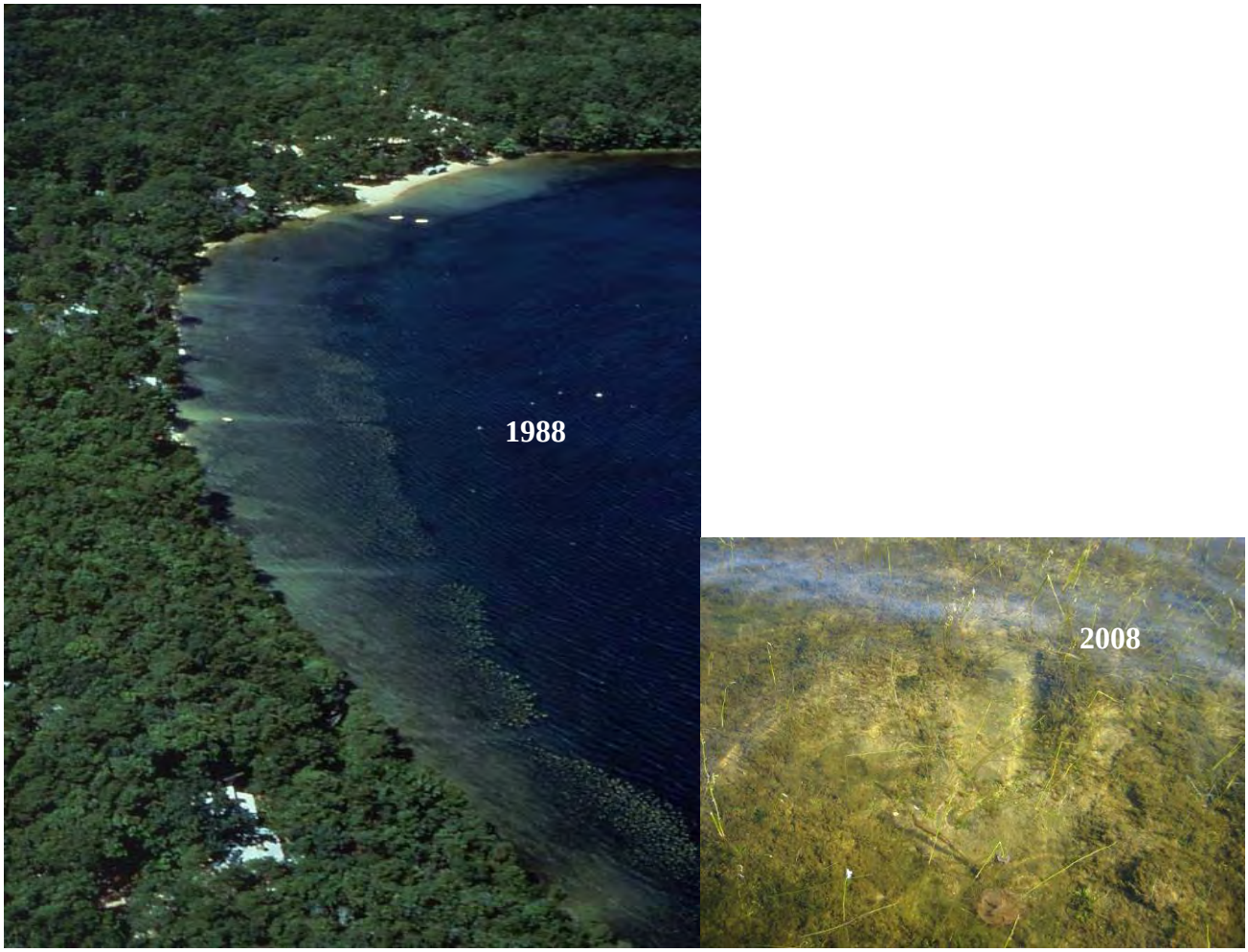


Above: NW side of Gull Pond on Sep 3, 2008 looking south towards the town landing (left). Note the extensive littoral zone vegetation adjacent to undeveloped upland. Much of this vegetation appears to be present in 1947 (right, dark signature).

In 1987 (20 years ago) aerial photographs show dense cover along the SW shoreline of Gull Pond. Today, the shoreline looks very similar, with emergent macrophytes, mosses, and periphyton covering most of the ground surface except where chunks of peat have been ripped away (waves? ice?) or where people have made pathways out to their boats and docks. In general, the current structure of the littoral zone here suggests that very little change has occurred over the last two decades.

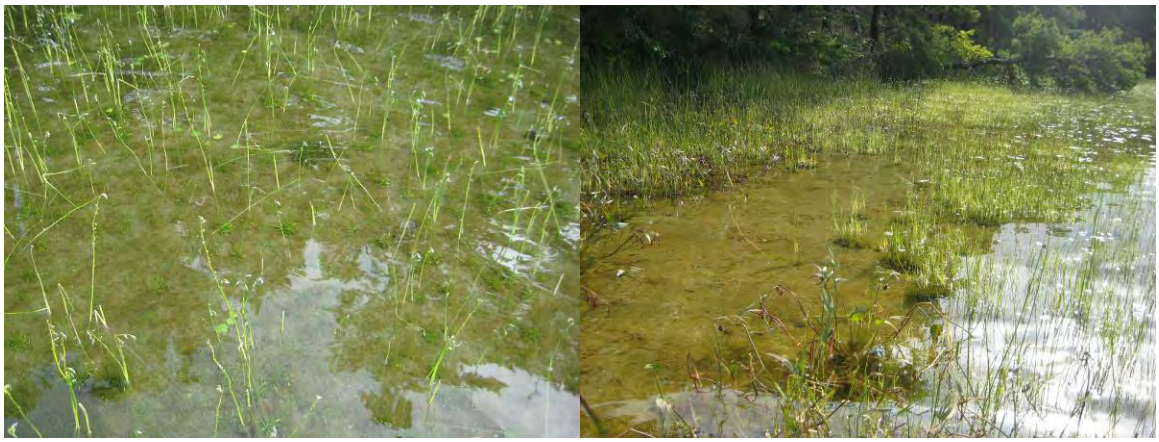


Above: Lobelia, Eleocharis, Drapanocladus, periphyton community along the SW shore in 1987 (top left) vs. 2000 (top right) and a photo of what this community looks like today (Sept 3, 2008) (bottom left & right).



Above: Aerial photo taken 20 years ago (1988) of the SW shoreline (left). This photo shows an extensive littoral zone macrophyte/periphyton community with a water lily fringe along the outer border (deepest water). The right side photo is representative of the community in this area today (Sept 3, 2008).

Present-day vegetation composition and comparison to other Wellfleet Ponds - The plant community along the NE shoreline of Gull Pond is dominated by *Lobelia dortmanna* (water lobelia) – a species considered to be an indicator of oligotrophic (pristine) conditions. In fact this plant is listed as a species of Special Concern in Rhode Island and Endangered in New Jersey. Other prominent species include *Eleocharis acicularis* and *Drapanocladus* moss. There is only scattered *Ponterdia cordata*. Periphyton clings to most of the Lobelia stems and forms a relatively solid cover over *Eleocharis* and *Drapanocladus* spp. In general, however, the macrophyte/periphyton community here does not appear any denser than in the rest of Gull Pond. The vegetation does extend farther out from shore, but this is only because the water remains shallow for a long ways toward the middle of the pond in this area. The emergent vegetation closely follows pond bathymetry - i.e., it stops abruptly when the water gets too deep.



Above: Sparse macrophyte cover and openings in macrophyte cover along the NE shoreline of Gull Pond (Sep 3, 2008)

Furthermore, the same kind of macrophyte/periphyton communities can be found in many other kettle ponds. In fact, ponds that are considered much more pristine (oligotrophic) than Gull Pond have just as much, if not more, littoral zone macrophytes and periphyton - except where human-related disturbance has occurred. In September of 2008, it was my observation that Great Pond (Wellfleet) had much higher amounts of periphyton attached to *Lobelia* and other aquatic plants than in Gull Pond.

Above: Periphyton algae on Lobelia (left) and extensive Lobelia stands (right) in Great Pond (Wellfleet) – a pond considered to be more oligotrophic and less impacted than Gull Pond. This shows that the growth of thick stands of Lobelia is likely a natural characteristic of these ponds.

Above: Vigorous littoral zone vegetation in Dyer (top left), Long (top right), Great-Truro (bottom left), and Ryder (bottom right) ponds. The distance that the vegetation extends into the ponds is dependent upon water depth (slope). Photos taken in late August 08.

Comparisons to other aquatic systems – It may also be helpful to consider Gull Pond from a broader perspective. The wetlands of Everglades National Park have some of the most oligotrophic conditions anywhere. Water column phosphorus is frequently undetectable across thousands of acres of this landscape. Nonetheless, aquatic vegetation and periphyton are essentially continuous while bare, vegetation-free zones are extremely rare or non-existent. Nutrient-poor bogs and acidic fens are also some of the most nutrient-poor aquatic systems as well as being extremely acidic. However, this does not limit the growth of plant species that are adapted to such conditions (see figure below). Even in systems classified as "ultra-oligotrophic", abundant littoral zone vegetation is a common occurrence where there are suitable substrates (i.e., not rocky bottoms), water depths, and light intensities

Making such comparisons reminds us that littoral zones that are completely devoid of plant cover (i.e., "an unblemished sand bottom") are extremely rare - even when conditions for plant growth are quite difficult. Bare substrate tends to occur where water depths limit establishment and growth, where there are high levels of physical disturbance, and/or where there is unsuitable substrate.

Above: Photos showing dense emergent vegetation in a sawgrass wetland in Everglades National Park (left) and an acidic bog in Maine (right) – both are oligotrophic systems in very pristine settings.

PAST RESEARCH AND MONITORING ON VEGETATION – WHAT DOES IT TELL US?

- Phytoplankton (floating algae suspended in the water column) productivity in Gull Pond has increased over the last 60 years based on soil core pigments analysis (Ludlam and Godfrey 1977). Whether this also translates to an increase in macrophyte growth in unknown.

- Hand drawn vegetation maps of Gull Pond in 1995 have areas that are labeled as "cleared due to human activity" (Roman et al. 2001) There are also notes on these maps that say "filamentous green algae on *Lobelia dortmanna* throughout area". So, in 1995 (13 years ago) there was apparently a significant amount of periphyton attached to macrophytes (as there is today). However, it is also obvious that human activity was preventing macrophyte growth from occurring over larger areas.

- Research has shown that N inputs can stimulate the growth of filamentous green algae in these kettle ponds (Smith and Lee, 2005). Unfortunately we have no historical data on periphyton growth in these ponds, but it is well within the realm of possibility that N inputs have increased the amount of algal growth in the pond (and other ponds).

- A comparison of species composition based on data from 5 linear transects (see map below) in Gull Pond showed no significant change (Smith 2008).

Above: Permanent vegetation monitoring transects originally established by Roman in 1995 (Roman 2001).

- There has been a small, but non-significant change in the total cover of herbaceous (non-woody) vegetation in Gull Pond between 1995 and 2005 (Smith 2008) along the 5 monitoring transects.

- There has been no change in the distance that macrophyte vegetation extends out into the middle of the pond along the 5 monitoring transects in Gull Pond.

- There has been a significant increase in the amount of organic matter in the top 10 cm of soil between 1995 and 2005. However, all ponds except Duck showed this trend, although there were higher levels of variability.

FACTORS THAT CONFOUND OUR ABILITY TO INTERPRET DATA AND RECONSTRUCT GULL POND'S NATURAL HISTORY

- Water levels – there can be enormous variability in emergent vegetation cover depending on water levels (higher = less cover)

- Human-related disturbance - what was the extent of "weeding" and activities that effectively cleared vegetation from in front of residences?

Other issues to consider:

- Has the growth of upland vegetation, particularly the forest, reduced wind velocities across the pond and, therefore, the amount of wave energy hitting the eastern shore of Gull Pond? Might this allow easier establishment and growth of plants there?
- Might the above change in the surrounding landscape reduce the amount of sand deposition from eroding upland banks into the littoral zone? Might this lead to a reduction in the amount of bare sand bottom?
- Might the above change in the surrounding landscape increase the amount of organic matter (particularly litterfall) that is deposited in the pond, thereby enhancing plant growth?
- Ice (especially during low water years) – the prevailing winds in the winter are from the NW, which would tend to push ice up on the east side of the pond. This can sometimes reshape the sandy bottom and influence vegetation patterns

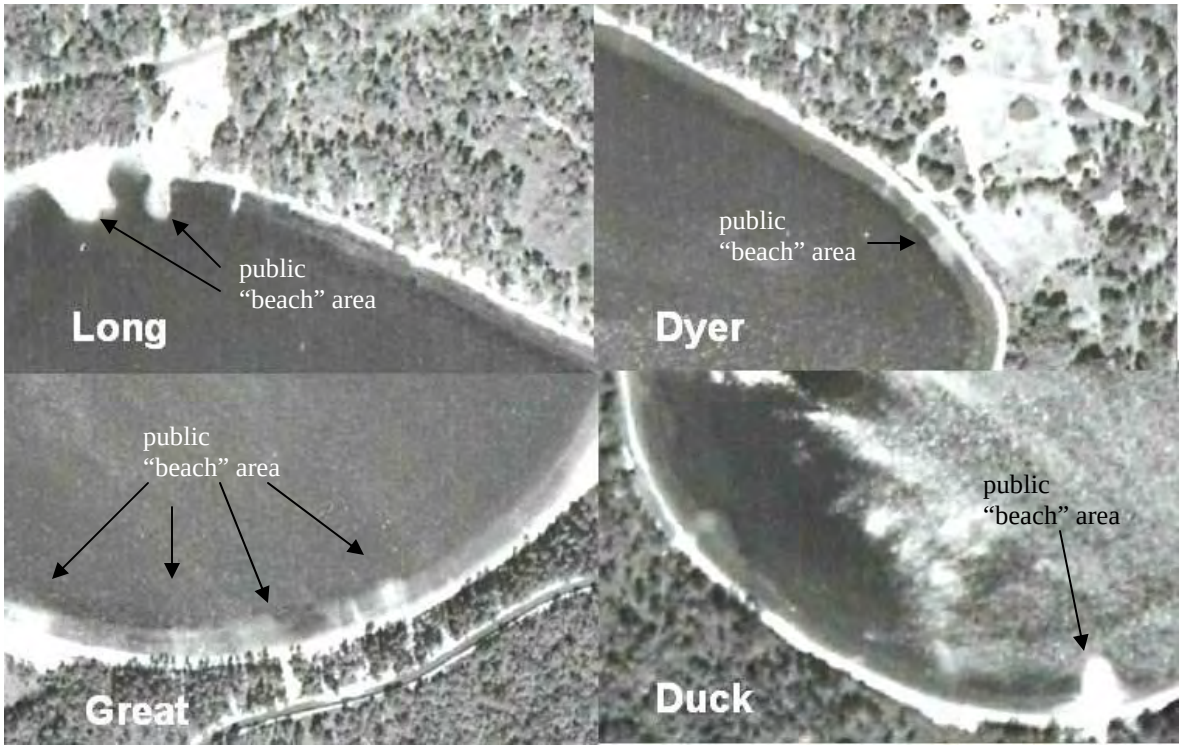
CONCLUSIONS:

While there is some evidence from the aerial photo series that an increase in vegetation/periphyton has occurred along the NE shoreline of Gull Pond, the rest of Gull pond's shoreline appears to have changed little. Unfortunately, it is difficult to reach a firm conclusion about vegetation trends due to the paucity of ground-level monitoring data as well as the confounding factors discussed above (particularly the history of disturbance/vegetation management that has gone on in the past). Part of the problem with the current system of vegetation monitoring there is that linear transects capture only a very small portion of the pond. In 2005, we added some additional larger plots (5 x 10 m) to provide better spatial coverage, but since these are new we cannot compare this data to any earlier surveys.

Nonetheless, the anecdotal observations of those who have lived in the pond are important sources of information. Many have witnessed a change in the character of the littoral zone. However, it may be that any changes may simply reflect recovery from past disturbance or natural succession, or both. In contemplating Gull Pond, and particularly the NE shoreline, I cannot think of any reasonable explanation why aquatic vegetation would not flourish

there. It is a very well lit, shallow shelf with soft substrate – all of which constitutes a highly suitable habitat for plant and algae growth. Moreover, Gull Pond has one of the highest pH values of any of the kettle ponds. The reduced acidity of this pond also makes it easier for plants to grow. For what it's worth, even in some of the earliest pictures I could find of Gull Pond (see postcard below) there are vigorous-looking stands of macrophytes along the shoreline – adjacent to a well-trampled "beach".

As a general rule, bare sand areas in kettle ponds usually correlate with some type disturbance. The disturbances could be human foot traffic, ice scouring (I've seen scoured bottom and shoreline sand berms formed by ice in these ponds), extreme water level fluctuations, etc. Human-caused discontinuities in ground cover stand out even in photos from 60 years ago (see figure below). It is my opinion that persistent bare sand areas that remain free of ground cover for long periods of time are not natural features of these kettle ponds. Disturbance may create these patches and once disturbed it may take a very long time for vegetation to recover, but if given a sufficient period of "calm" these areas should be eventually be re-colonized.



Above: 1947 aerial photographs showing human-related disturbances that cause discontinuities in littoral zone ground cover.

Finally, it is worth re-visiting a point made earlier. That is, other ponds in Wellfleet that are much less developed and have more oligotrophic conditions (e.g., Great Pond in Wellfleet) have extensive stands of *Lobelia* and other emergent macrophyte species (*Juncus militaris*) as well as periphyton. This strongly suggests that the development of these communities is a natural process and is not indicative of eutrophication or other

human-related effects on the ponds. That said, progressive and significant increases in macrophyte cover and stature or a significant changes in species composition at undisturbed sites would be worrisome. The initiation of our long-term vegetation monitoring program and a heightened awareness of Gull Pond issues should go a long way toward reaching a firm conclusion on this matter. In the meantime, I would not be overly concerned about the growth of vegetation in the littoral zone of Gull Pond. Unless, a dramatic increase in plant density, biomass, or a significant species shift occurs, I would not suspect that something peculiar is going on there.

Above: Postcard photo of the south/southwest shore of Gull Pond in early 1900s showing a stand of emergent macrophytes in the littoral zone that extends a considerable distance down the shoreline.

References

Ludlam and Godfrey 1977

Roman, C. T., N. E. Barrett, & J. W. Portnoy, 2001. Aquatic vegetation and trophic condition of Cape Cod (Massachusetts, USA) kettle ponds. Hydrobiologica 443: 31-42

Smith, S.M. 2008. Vegetation Monitoring Protocol for Kettle Ponds of Cape Cod National Seashore. NPS Report. Cape Cod national Seashore, Wellfleet, MA.