Regime shift in the littoral ecosystem of volcanic lake Atitlán in Central America: combined role of stochastic event and invasive plant species

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ABSTRACT

Different functional groups of macrophytes vary in their impact on aquatic ecosystem structure and processes. The introduction of new species with different growth form, combined with a stochastic event, may have serious and irreversible consequences for lake functioning. Two coinciding events happened in the littoral of Lake Atitlán: invasion by a submersed macrophyte, *Hydrilla verticillata,* followed by a rapid increase in the lake water level (> 2.5 m). The native emergent species, *Schoenoplectus californicus* was generally not able to survive such a rapid water level increase, *Hydrilla* spread and formed dense mats preventing *Schoenoplectus* regeneration. The impact of the free floating *Eichhornia crassipes*, was more localized, despite its much longer presence at the lake. Although the three species have comparable standing biomass, the two invaders show lower C:N and N:P ratios than *Schoenoplectus* resulting in faster decomposition rates and indicating shifts in nutrient cycling within the ecosystem. The oxygen profile of the water column has been altered by the non-native species in a significantly different manner: in *Eichhornia*, the oxygen drops down to 30-50%, while the supersaturation occurs in *Hydrilla*. Both *Schoenoplectus* and *Eichhornia* patches exhibit comparable carbon dioxide (CO_2) fluxes, sequestering 230 and 300 mg CO_2 $m^{-2}h^{-1}$ respectively during the day and emitting 250 and 200 mg CO_2 $m^{-2}h^{-1}$ respectively during the night. *Hydrilla* patches sequester CO_2 during the day (34 mg CO_2 $m^{-2}h^{-1}$) aa well as at night (44 mg CO_2 $m^{-2}h^{-1}$). The invasive species maintain a richer community of macroinvertebrates compared to native species, both in taxa diversity and numbers of individuals. Management plans need to consider the negative impacts of introduced species balanced against their beneficial effects.

ACKNOWLEDGEMENT

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OBJECTIVE:

To evaluate the impact of combined events of rapid water level increase and invasion by *Hydrilla verticillata* on ecosystem processes in the littoral of Lake Atitlán in terms of:

- Change in macrophyte diversity
- Biomass production and nutrient cycling
- Impact on physical and chemical properties of water
- Carbon sequestration/emission
- Habitat quality for macrinvertebrates.

METHODS

- Lake Atitlán is a volcanic lake located in the highlands of Guatemala (altitude 1555 m, mean depth 183 m, surface area 137 km^2). It is a nitrogen limited hardwater lake, which has transitioned from oligotrophic to mesotrophic during the last decade. Littoral zone covers about 4% of the lake.
- To evaluate the impact of *Hydrilla* between the initial stages of invasion and present, we compared species presence and abundance in three transects out of nine originally surveyed in 2006 (Ríos-Palencia 2007).
- We combined repeated macrophyte biomass sampling with measurements of physical and chemical properties of water at numerous locations in the lake's littoral (Fig. 2 & 4).
- Transparent floating chambers (Fig. 5) were used to measure gas fluxes both in the lake and in the mesocosms (Fig. 3) Gas samples were analyzed for CO_2 and CH_4 concentrations using a Shimadzu GC-2014 greenhouse gas analyzer.
- Macroinvertebrate diversity and abundance in monospecific macrophyte stands were assessed semi-quantitatively in May and September of 2014.

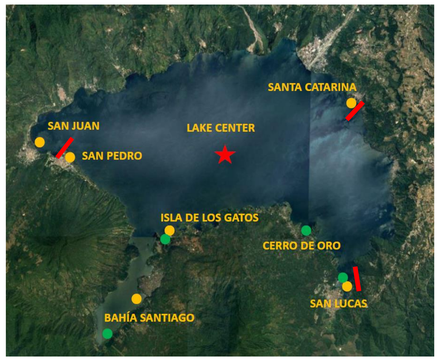

Fig. 1 Locations of sampling sites at Lake Atitlán. Yellow dots – macrophyte sampling; green dots – macroinvertebrate sampling; red lines – species diversity sampling

Fig. 2 Dissolved oxygen measurements in the stand of *Eichhornia* crassipes

Fig. 3 Mesocosms with *Schoenoplectus, Hydrilla, Eichhornia* and control

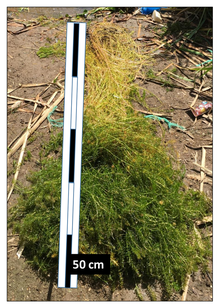

Fig. 4 *Hydrilla* plants collected from ¼ m^2

Fig. 5 The chamber for gas fluxes measurements

RESULTS

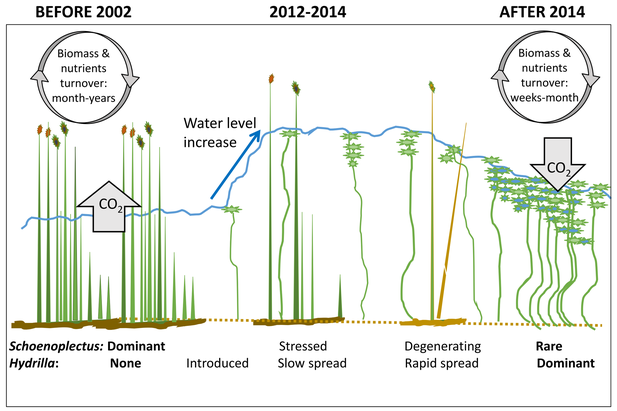

Fig. 6 Replacement of *Schoenoplectus californicus* by invasive *Hydrilla verticillata* in the littoral zone of Lake Atitlán. *Schoenoplectus* was not able to persist at depths > 5 m for longer than 3 y. Following the loss of *Schoenoplectus, Hydrilla* spread and became established into the abandoned habitat. Its dense canopy now intercepts the majority of the incoming light, and inhibits the growth of other plants, including *Schoenoplectus*.

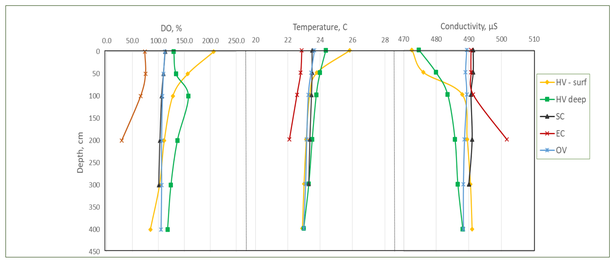

Fig. 8 Mean values of depth profiles of dissolved oxygen, water temperature and conductivity in stands of *Schoenoplectus* (SC), (HV) and *Eichhornia* (EC) in July 2017 at San Lucas, Santa Catarina and San Pedro. HV – surf indicates values for a stand where the canopy is breaking water surface, HV – deep indicates stands with the canopy 50-150cm below the water surface.

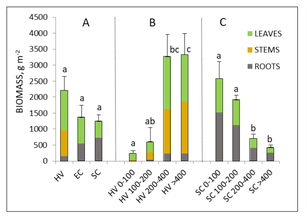

Fig. 9 Biomass of *Hydrilla* (HV), *Eichhornia* (EC) and *Schoenoplectus* (SC). (A) Average values over all sampling locations, 2015-17. (B) Average biomass of HV for discrete depth ranges (2017). (C) Average biomass of SC for discrete depth ranges (2010-2012).

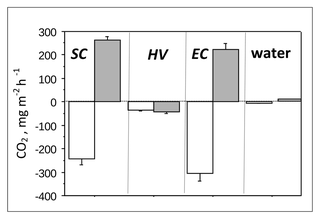

Fig. 10 Effects of macrophyte species on CO_2 fluxes. White and grey columns represent CO_2 fluxes during day and night, respectively. SC = *Schoenoplectus*, HV = *Hydrilla*, EC = *Eichhornia*, water = open water.

Fig. 7 Healthy stand of *Schoenoplectus* near San Juan in 2002; the same area in 2015, dominated by *Hydrilla* with *Schoenoplectus* completely missing. Lake Atitlán, Guatemala.

CONCLUSIONS

- **The switch from low-productive littoral zones dominated by *Schoenoplectus* to high-productive zones dominated by *Hydrilla* represents a major acceleration of biogeochemical cycling in the lake littoral.**
- ***Hydrilla* changed the oxygen saturation and carbon cycling of the littoral zone with an overall impact on the lake O and C balance proportionally greater than would be expected based on spatial extent alone.**
- **Preliminary data indicate an important role of N-fixation by both autotrophic and heterotrophic fixers in epiphytic biofilms on leaves and stems of *Hydrilla*** (Poster #1)
- **The highly saturated oxygen conditions and structured habitat of HV make its stands ideal environment for macroinvertebrates and fish.**