UVic Sustainability Scholars Program

Invasive “Parrot’s Feather” Plant Species in Somenos Creek: Life Cycle, Growth, and Interaction with Yellow Pond Lily and Smartweed

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Disclaimer:

This report is a product of the UVic Sustainability Scholars Program, a partnership between UVic and various on- and off-campus organizations offering internship opportunities to graduate students working on sustainability-focused research projects that advance sustainability in the region. This project was conducted under the mentorship of Somenos Marsh Wildlife Society staff.

Territorial Acknowledgement:

I acknowledge that fieldwork for this project took place on the unceded territory/ancestral lands of the Quw’utsun Nation.

I acknowledge and respect the lək̓ʷəŋən peoples on whose territory this report was written, and the Songhees and Esquimalt peoples whose historical relationships with land continue to this day.

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1) Introduction and Overview

This study investigates growth of PF in Somenos Creek, exploring possible explanations for growth distribution, and interaction with other aquatic plants. As such, it looks to investigate these distinct but related questions:

1) What makes PF growth and spread across and along the Creek so effective?
2) What factors explain PF's presence/absence in certain areas (esp. headwaters versus downstream)?
3) What explains the distribution/interaction of PF's growth and presence with other aquatic plants?

My methodology consists of literature review in aquatic botany, including past empirical research conducted by Somenos Marsh Wildlife Society (SMWS) experts in aquatic biology. The question of presence/absence and interaction with Yellow Pond Lily and Smartweed are explored as part of ongoing discussion and associated water quality fieldwork conducted at Somenos Creek from May-July 2024. As such, this paper offers preliminary conclusions with an intent to guide further research:

- As an invasive plant species transported to North America, PF's growth strategy originally adapted to tropical South America. PF may leverage associated competitive growth strategies in eutrophic North American habitats, like Somenos Creek.

- Removal of riparian vegetation for development activities increases sunlight exposure, detrital buildup and leaching, and urban and agricultural run-off, contributing to PF growth by increasing nutrient availability.
- The absence of PF growth at the tributary, Richards Creek, despite high Phosphorus, may point to introduction at an intermediate area of Somenos Basin, e.g., Somenos Lake or Somenos Creek.
- The disappearance of PF at headwaters of Somenos Creek may be explained by out competition of Yellow Pond Lilies. At intermediate waters, both plants grow separated on either side of the Creek. On the other hand, Smart Weed grows near PF.

Noting empirical literature on PF, and fieldwork and study by SMWS, Section 2 outlines PF's lifecycle, spread, and impact in Somenos Creek. As an invasive plant, PF stops boat travel, causes near-zero water column oxygen levels, threatens fish survival, and limits neighbouring plant growth.

Section 3 examines factors explaining PF's invasion success. Subsection A examines ecosystem characteristics that render Somenos Creek more vulnerable to proliferation of invasive species like PF upon introduction. Subsection B reviews literature in aquatic botany examining PF growth adaptations under varying nutrient and light conditions in fieldwork and lab studies. Subsection C examines interaction between PF and native plant communities, focusing on the role of allelopathy, and competitive growth mechanics of two successful native plants, Yellow Pond Lily, and Smartweed.

2) <u>Parrot's Feather ("PF") Lifecycle, Spread, and Impact in Somenos Creek</u>

A. Lifecycle and Spread

PF is an aquatic plant native to South America, transported through international trade in ornamental pond and aquarium plants.[1] Following first observation at Somenos Creek in 2014, PF reached nuisance levels of coverage within a year, stopping boat travel in 2015.[2] More recently, PF reaches "over 70% [coverage] of the creek during high season in July and August" with 100% coverage across intermediate transections of the creek.[3]

As an aquatic plant, PF consumes CO2 and respires oxygen to the atmosphere,[4] with relatively less oxygen respired to the water column.[5] "Gross photosynthesis" measures "the rate at which light energy is converted to chemical energy, transforming water and carbon dioxide (CO2) into organic carbon and oxygen".[6] Inorganic carbon in the form of dissolved carbon dioxide (CO2) and bicarbonate (HCO3) are "the primary source of carbon for photosynthesis".[7] Water temperature also affects the growth of PF through carbon uptake.[8]

During the summer, PF grows to form a thick mat spreading across Somenos Creek's water surface. Floating leaves of roots and shoots maximize photosynthetic CO2 uptake across

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[1] Lauren M. Kuehne, Julian D. Olden & Erika S. Rubenson, "Multi-trophic impacts of an invasive aquatic plant" (2016) 61 Freshwater Biology 1846 at 1846.

[2] Dave Preikshot, "Management Options, Monitoring Programs, and Research Designs for Controlling Parrots Feather in Somenos Creek" (2019) Report Submitted to North Cowichan Municipality by Somenos Marsh Wildlife Society and Madrone Environmental Services 1 at 3.

[3] Adam Dewar, "2021 Somenos Creek Parrot's Feather Report" (2021) Somenos Marsh Wildlife Society 1; Adam Dewar & Gina Hoar, "Somenos Creek Parrot's Feather Report" (August 2021) Somenos Marsh Wildlife Society 1.

[4] Preikshot, *supra* note 2 at 13.

[5] Robert G. Wetzel, *Limnology: Lake and River Ecosystems* (Elsevier Science, 2001) at 538.

[6] Geneviève M Carr, Harnish C Duthie, & William D Taylor, "Models of aquatic plant productivity: a review of the factors that influence growth" (1997) 59:3-4 Aquatic Botany 195 at 198.

[7] Wetzel, *supra* note 5 at 187.

[8] Nuoxi Wang et al, "Effects of water temperature on growth of invasive *Myriophyllum aquaticum* species" (2024) 19:2 Aquatic Invasions 153.

leaf surface, in extension with mat structure.[9] In competitive macrophyte environments, CO2 in the water column is "often limited" due to high photosynthetic activity, and CO2's "extremely reduced diffusion in water".[10]

At the same time, submerged leaves are shed to produce adventitious (aquatic) roots, capable of CO2 and other nutrient uptake from the water column.[11] The elongation of stems into shoots along the water surface "forces the lower, older portions of the emergent stem beneath the water surface".[12] Emergent stems on the water surface show higher rates of photosynthesis than submerged growth forms (stolon/shoots).[13] Stolon and rooted rhizomes allow for additional nutrient uptake from sediment.[14]

In Somenos Basin, PF "does not grow well" from October to early April, when water temperature drops below 8°C.[15] During the Fall, senescence of the mat structure's underside causes fragmentation, allowing spread of potential clones along the water surface.[16] Moderate disturbance, wind exposure and streamflow facilitate clonal spread across the water surface

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[9] Ana Carlota Eusebio Malheiro, Peter Jahns & Andreas Hussner, "CO2 availability rather than light and temperature determines growth and phenotypical responses in submerged *Myriophyllum aquaticum*" (2013) 110 Aquatic Botany 31 at 32.

[10] Daniela Erhard, "Allelopathy in Aquatic Environments" in Manuel J Reigosa, Nuria Pedrol, & Luis González, eds, *Allelopathy: A Physiological Process with Ecological Implications* (Springer, 2006) 433 at 433; See also Wetzel, *supra* note 5 at 187-88.

[11] Mark D. Sytsma & L.W. J. Anderson, "Transpiration by an emergent macrophyte: source of water and implications for nutrient supply" (1993) 271 Hydrobiologia 97 at 98-9; Bingchang Tan et al, "Eutrophic water or fertile sediment: which is more important for the growth of invasive aquatic macrophyte *Myriophyllum aquaticum*?" (2018) 419:3 Knowledge & Management of Aquatic Ecosystems 1 at 1.

[12] Sytsma & Anderson, "Transpiration", *supra* note 11 at 98-9.

[13] Malheiro, Jahns, & Hussner, *supra* note 9 at 31; Euphresco DeClaim, "A State-of-the-art June 2011: *Myriophyllum aquaticum* (Vell.) Verdcourt" (2011) Report prepared for Plant Protection Service Aquatic Ecology and Water Quality Management Group, Centre for Ecology and Hydrology, Wageningen University, Netherlands 1 at 10, online (pdf): *Q-bank Invasive Plants* <https://q-bankplants.eu/Controlsheets/Myriophyllum_State-of-the-Art.pdf>.

[14] Tan et al, *supra* note 11 at 1; Xiaolong Huang et al, "The root structures of 21 aquatic plants in a macrophyte-dominated lake in China" (2018) 11:1 Journal of Plant Ecology 39 at 42.

[15] Preikshot, *supra* note 2 at 14.

[16] DeClaim, *supra* note 13 at 15.

before establishing roots.[17] Winter frost causes damage to emergent leaves,[18] but PF rhizomes survive the winter in terrestrial and underwater sediment.[19] A study in California finds greater biomass in submerged growth form during the winter.[20]

B. Impact

Fieldwork and monitoring at Somenos Creek suspect PF's submerged shoots pose a potential barrier to fish migration.[21] However, overriding water quality concerns threaten fish and other aquatic plant survival, linked to PF growth and spread.[22]

PF's dense mat structure restricts light penetration through the water column, "excluding native plants".[23] At the same time, PF's floating mat structure limits diffusion between air and water, reducing atmospheric oxygenation of water.[24]

This is especially relevant to Somenos Creek's historically poor drainage due to "the slight difference in stream bed elevation between the head and mouth of Somenos Creek".[25]

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[17] Ryan M. Wersal, J.D. Madsen, & P. D. Gerard, "Survival of parrotfeather following simulated drawdown events" (2013) 51 Journal of Aquatic Plant Management 22; Dong Xie et al, "The propagule supply, litter layers and canopy shade in the littoral community influence the establishment and growth of *Myriophyllum aquaticum*" (2013) 14 Biological Invasions 113 at 114-15; R. M. Wersal & J.D. Madsen, "Comparative effects of water level variations on growth characteristics of *Myriophyllum aquaticum*" (2011) 51 Weed Research 386 at 387.

[18] DeClaim, *supra* note 13 at 16; Preikshot, *supra* note 2 at 15, citing DeClaim, *supra* note 13 at 16; Life cycle studies in California observe that stems emerge onto the water surface in Spring, with increasing density of elongated shoots "until frost": Sytsma & Anderson, "Transpiration", *supra* note 11 at 98-9.

[19] DeClaim, *supra* note 13 at 16; Mark D. Sytsma & L. W. J. Andersen, "Biomass, Nitrogen, and Phosphorus Allocation in Parrotfeather (*Myriophyllum aquaticum*)" (1993) 31 J. Aquat. Plant Manage. 244 at 244; Wersal & Madsen, "Comparative effects", *supra* note 17 at 388.

[20] Sytsma & Andersen, "Biomass, Nitrogen, and Phosphorus", *supra* note 19 at 244.

[21] Adam Dewar & Gina Hoar, "Parrot's Feather Mat Assessment" (11 August 2021) Somenos Marsh Wildlife Society 1 at 4.

[22] *Ibid* at 4; See Gina Hoar, "Late Summer – Fall 2022: Parrot's Feather Update" (14 November 2022) Somenos Marsh Wildlife Society 1 at 18.

[23] Preikshot, *supra* note 2 at 15-6.

[24] *Ibid* at 13; Nina Caraco et al, "Vascular Plants as Engineers of Oxygen in Aquatic Systems" (2006) 56:3 BioScience 219.

[25] Preikshot, *supra* note 2 at 5.

Decaying plant, animal, and microbial matter at the bottom of the creek collects because of low streamflow and low oxygen in the water column.[26]

For example, senescent leaves "slough off" living plants and collect in sediment.[27] Phosphorus leaches from leaves, as part of nutrient cycling with plant growth and decay (See Figure 13-9 below, reproduced from Wetzel, pg. 255).[28] Decaying plant "detritus" is regularly decomposed by microorganisms to produce CO2, but this process requires oxygen.[29] Buildup of detrital plant matter further increases oxygen demand, amid scarce oxygen availability.[30]

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[26] M. Zimmer, "Detritus" in SE Jørgensen & BD Fath, eds, *Encyclopedia of Ecology* (Oxford University Press, 2008) 903 at 908.

[27] Wetzel, *supra* note 5 at 254.

[28] *Ibid* at 255; See also Arif J. Siddiqui et al, "Macrophytes and Their Role in Wetland Ecosystems" in Sanjeev Kumar et al, eds, *Aquatic Macrophytes: Ecology, Functions, and Services* (Springer Nature, 2023) 119 at 125-26.

[29] M. Zimmer, *supra* note 26 at 908; M. F. Nunes, M. B. Cunha-Santino, & J. R. Bianchini, "Aerobic mineralization of carbon and nitrogen from *Myriophyllum aquaticum* (Vell.) Verdc. Leachate" (2007) 19:3 Acta Limnologica Brasiliensia 285.

[30] M. Zimmer, *supra* note 26 at 908; Rachel Schultz & Eric Dibble, "Effects of invasive macrophytes on freshwater fish and macroinvertebrate communities: the role of invasive plant traits" (2012) 684 Hydrobiologia 1 at 6; See Jorge Poveda, "The use of freshwater macrophytes as a resource in sustainable agriculture" (2022) 369:133247 Journal of Cleaner Production 1 at 2.

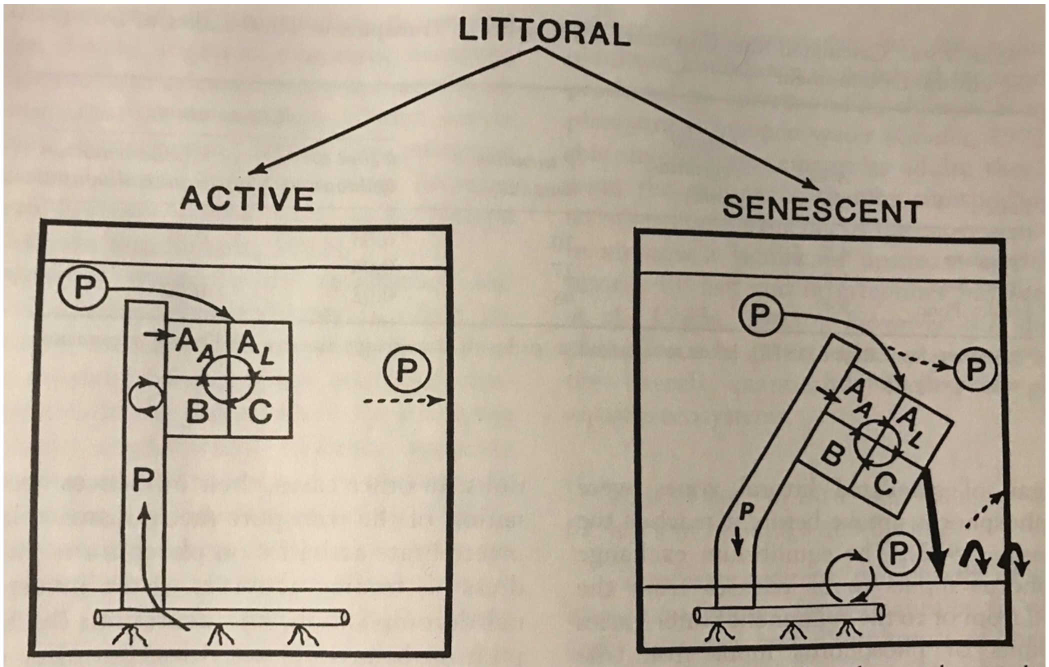

FIGURE 13-9 Fluxes of phosphorus (P) from the sediments to submersed littoral macrophytes and among the epiphytic microflora of the periphyton. A_A = adnate algae; A_L = loosely attached algae, B = bacteria; and C = inorganic or organic particulate detritus, such as calcium carbonate. (From Wetzel, 1990a.)

Anoxic conditions in the water column and dense mat structure directly threaten fish species but also the growth of biodiverse aquatic plants in Somenos Creek. As will be discussed later, two plants appear capable of competing with PF, in resisting or adapting to monotypic growth mats. The following section discusses factors implicated in PF's success as an invasive species at Somenos Creek.

3) Factors Explaining PF Invasion and Plant Resistance

Noted in recent 20-year study of PF in Washington, USA on the Chehalis River,[31] "Key determinants" of invasive aquatic plant growth and impact include:

1) Interaction between recipient ecosystem conditions and growth strategy of invasive aquatic plants,
2) Invasive growth mechanics that "elevate the likelihood of negative effects", especially capacity for "resource use efficiency and increased growth rates, allelopathy and phenotypic plasticity",[32] and
3) Cascading changes in habitat, including competition between neighbouring plant communities.[33]

Using these determinants as a guide alongside other empirical literature, each subsection respectively investigates recipient ecosystem characteristics, PF growth traits, and interaction with neighbouring plants.

A. Recipient Ecosystem Conditions: Shallow Water Depth, Low Flows, Increased Nutrient Load, and Light Exposure Increase Risk of Invasive Growth

Ecosystem change can create opportunities for invasion, where characteristics of recipient ecosystems and invading species interact.[34] Preikshot identifies re-channelization and

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[31] Kuehne, Olden & Rubenson, *supra* note 1 at 1847; See Lauren M. Kuehne et al, "Twenty year contrast of non-native parrotfeather distribution and abundance in an unregulated river" (2022) 849 Hydrobioblogia 899.
[32] Kuehne, Olden & Rubenson, *supra* note 1 at 1847.
[33] *Ibid;* Xie et al, *supra* note 17 at 114-15; Jonathan P. Fleming et al, "Weak non-linear influences of biotic and abiotic factors on invasive macrophyte occurrence" (2021) Aquatic Invasions 349.
[34] Gabrielle Thiébaut & Laurent Martinez, "An exotic macrophyte bed may facilitate the anchorage of exotic propagules during the first stage of invasion" (2015) 746 Hydrobiologia 183 at 184.

associated removal of riparian vegetation for urban and agricultural development as setting key conditions for PF's invasion success upon introduction in 2014.[35]

Lack of shading originally provided by riparian tree canopy increased aquatic plant proliferation in these areas, corresponding with early reports of pond lily barriers to boat travel in the 1940s.[36] Similarly, Canary Reed Grass, originally introduced as an agricultural product, eventually overtook areas occupied by canopy tree growth, providing little shade to riparian areas and less opportunity for tree growth.[37]

The "persistent" and "abundant" growth of aquatic plants in Somenos Creek led to past dredging of the Creek to remove overgrown plant material and improve Creek flow for agriculture and travel.[38] Yet as noted in water quality monitoring from 2003-05 and 2021, urban and agricultural development continues to "contribute significant nutrient loads to the Somenos Basin",[39] likely facilitating PF's spread and growth.

As such, physical and chemical factors influence growth, including nutrient content, waterflow velocity and column depth, light availability, and water temperature.[40] In lab experiments comparing PF growth rates in high versus low nutrient substrates, alongside varying water depth, substrate nutrients limited growth performance at water depths "up to 75 cm".

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[35] Preikshot, *supra* note 2 at 1; See Carla Vander Sluys, *Agricultural Land Drainage in British Columbia: The Richards Creek-Somenos Creek Example* (MA Thesis, Natural Resources Management, McGill University, 1986) at iii.

[36] Preikshot, *supra* note 2 at 7; personal communication.

[37] Kyle Rasmussen, "Restoring Wetlands in the Somenos Basin" (August 31, 2012) Report Prepared for Somenos Marsh Wildlife Society 1 at 6, 23; Preikshot, *supra* note 2 at 13.

[38] Preikshot, *supra* note 2 at 9.

[39] See E. Guimond & M. Sheng, "A Summary of Water Quality Monitoring in the Somenos Basin, 2003-2005" (November 2005) Report Prepared for Pacific Salmon Commission, Vancouver BC at ii; Gina Hoar, "S'amunu|Somenos Water Quality Report" (2021) Somenos Marsh Wildlife Society 1 at 2, 15.

[40] Konstantin Ochs et al, "Flow Management to Control Excessive Growth of Macrophytes – An Assessment Based On Habitat Suitability Modeling" (2018) 9:356 Frontiers in Plant Science 1 at 2, 6.

However, substrate nutrients did not increase or decrease growth rates when water depth increased beyond 75cm, suggesting greater influence of light availability.[41]

Indeed, PF prefers shallow areas, usually no deeper than 2m.[42] Submersed leaves receive less light at increasing depth, reflected in decreasing total plant length when controlled and measured in laboratory experiments.[43] Further, "zonation along a depth gradient is often observed as a function of light availability",[44] where "low light intensities determine the maximum depth of plant growth due to the limitation of overall photosynthesis".[45]

A minor slope in gradient change from the head to the mouth of the Creek, associated low streamflow conditions, and high light exposure in Somenos Creek,[46] point to analogous explanations in Washington, USA of PF's "establishment and abundance" in "areas of low discharge, shallow depth, and high availability of light; when these factors are all present [PF] can become dominant or monotypic".[47]

Consider that in PF's native tropical environment of Parana River Basin, Brazil, low nutrient loading in the headwaters alongside higher shading and water flow, impose "physical and nutritional barriers" on the development of PF, relative to lower river areas.[48] On the other hand, within Brazil's Ourinhos reservoir, nutrient loading in the water column is not a significant

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[41] Xiaoliang Zhang et al, "Moderate hydrological disturbance and high nutrient substrate enhance the performance of Myriophyllum aquaticum" (2021) 848 Hydrobiologia 2331 at 2340.

[42] Sytsma & Andersen, "Biomass, Nitrogen, and Phosphorus", *supra* note 19 at 244; Ryan M. Wersal & John D. Madsen, "Aquatic plants, their uses and risks: A review of the global status of aquatic plants" (Report prepared for the UN Food and Agriculture Organization, 2012) at 25.

[43] Wersal & Madsen, "Comparative Effects", *supra* note 17 at 386.

[44] John D. Madsen & R. M. Wersal, "A review of aquatic plant monitoring and assessment methods" (2017) 55 J. Aquat. Plant Manage. 1 at 2.

[45] Malheiro, Jahns, & Hussner, *supra* note 9 at 31.

[46] Preikshot, *supra* note 2 at 1; Pamela Williams & Gillian Radcliffe, "Somenos Management Plan" (August 2001) Report Prepared for Somenos Steering Committee by Madrone Consultants Ltd. 1 at 15.

[47] Kuehne et al, *supra* note 31 at 900.

[48] R.S.T. Moura & G.G. Henry-Silva, "Is there a zonation pattern in aquatic macrophytes communities in the aquatic environments of the Brazilian semiarid?" (2018) 41 Brazilian Journal of Botany 665 at 665.

factor determining PF's growth distribution among other native plants.[49] Rather, in ecosystems with high nutrient availability like P and N, the primary factors driving growth pattern and distribution include water turbulence, shading, and wind exposure relative to other native plant species.[50]

The following section examines PF's adaptive growth mechanics in terms of these nutrients. PF growth is not limited by nutrient availability given abundance in Somenos Creek. Rather, PF may leverage growth mechanisms originally adapted to high nutrient environments like tropical Brazil with other similarly competitive species.

B. Growth Adaptations

i) Hydrological Disturbance

As part of Somenos Basin's natural conveyance system of water flow, Somenos Creek is fed by water flowing from Somenos Lake and three tributary streams. The tributary streams, Bings, Averill, and Richards Creek, flow into Somenos Lake, with southern Lake drainage forming the headwaters of Somenos Creek (See Figure 1 - Map of Somenos Basin below, adapted from SMWS website).[51] PF's "likely mode of introduction" in Somenos Creek is dumping of pond or aquarium fragments at some point in this system.[52]

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[49] M.B. Cunha-Santino et al, "Morphometry and retention time as forcing functions to establishment and maintenance of aquatic macrophytes in a tropical reservoir" (2016) 76:3 Braz. J. Biol. 673 at 673.

[50] *Ibid* at 673.

[51] Rasmussen, *supra* note 37 at 3.

[52] Preikshot, *supra* note 2 at 17.

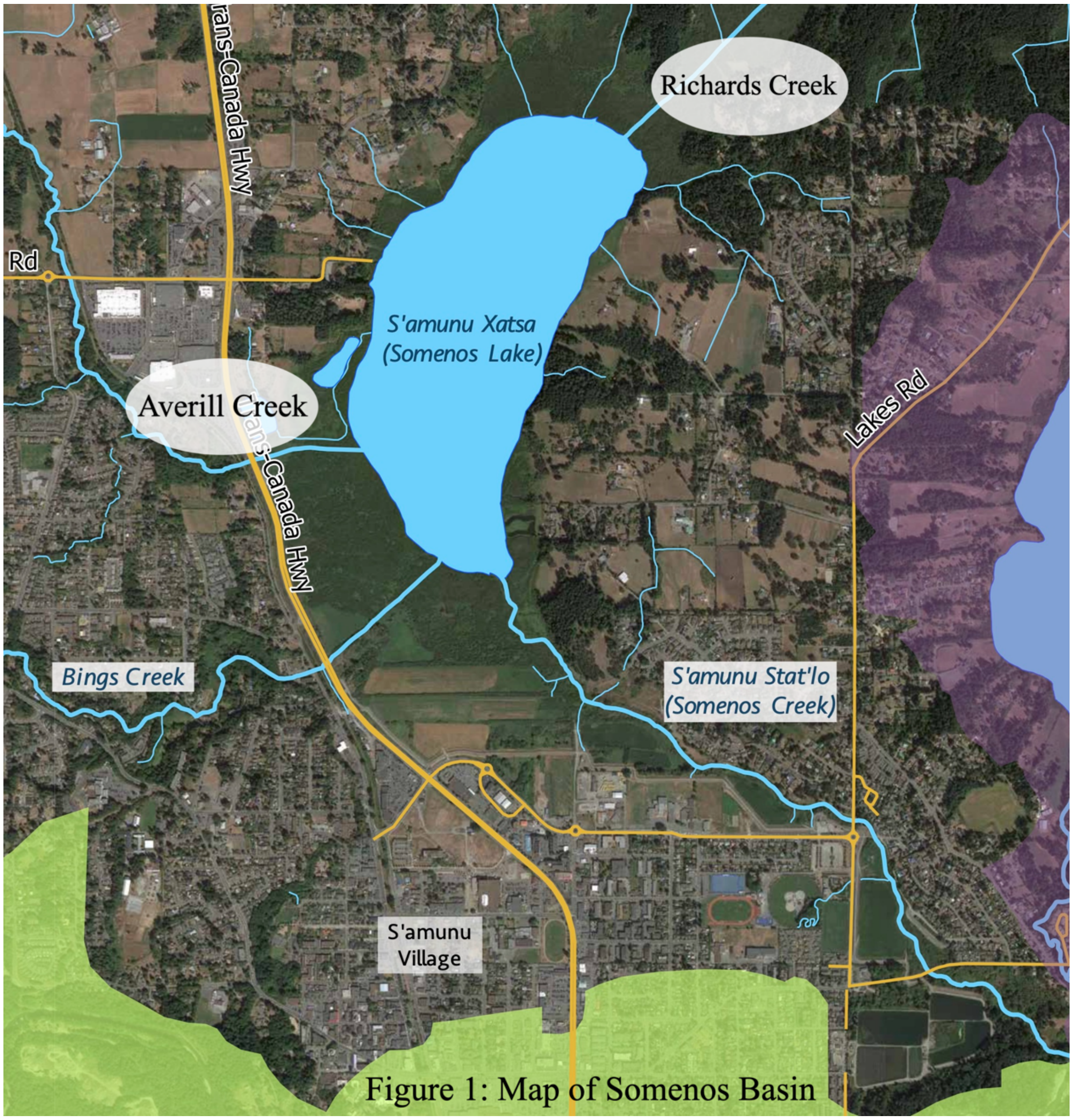

Figure 1: Map of Somenos Basin

A general framework for modelling the growth of aquatic plants measures the "rate of biomass production through gross photosynthesis" in balance with "biomass loss due to respiration [and] plant washout and decay".[53] As such, ecosystem hydrology impacts the "distribution and abundance" of PF as a function of "biomass gain and loss processes", subject to the intensity of flood events and river flow, and growth during suitably stable periods.[54]

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[53] Carr, Duthie, & Taylor, *supra* note 6 at 197.
[54] Ochs et al, *supra* note 40 at 2.

Simulated water drawdown in the laboratory shows that lack of overlying water reduces nutrient availability in the water column, and "expos[es] stolons and adventitious roots to dessication".[55] As such, the drag force of rain events can "cause stem breakage and uprooting of plants" from sediment, and root access to nutrients.[56] With regard to Somenos Creek, PF can tolerate periodic disturbance,[57] "growing on partially dried riparian habitat" that "give it a head start on other species before flooding events or during low water availability periods".[58]

At the same time, "moderate hydrological disturbance" can aid the distribution of asexual propagules and enhance likelihood of successful establishment.[59] In a laboratory study, the water exchange rate directly affected dissolved oxygen concentration, stimulating root growth and enhancing P and N absorbing abilities.[60]

ii) Nutrient Uptake in Eutrophic Waters

N, P, CO2 and bicarbonate (HCO3-) are key nutrients in the photosynthetic growth and decay cycle of aquatic macrophytes, including PF.[61] N, P, and carbon are all "major constituents of the cellular protoplasm of organisms", including symbiotic photosynthetic microorganisms, as part of nutrient cycling across aquatic plant growth and decay *in situ*.[62] They are also involved in

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[55] Wersal, Madsen, & Gerard, *supra* note 17 at 22.

[56] Ochs et al, *supra* note 40 at 2, 6.

[57] Guyo Duba Gufu, Anthony Manea, Michelle R. Leishman, "Responses of five naturalized ornamental freshwater plant species to elevated carbon dioxide concentration and nutrient enrichment" (2020) 847 Hydrobiologia 3487 at 3488.

[58] Preikshot, *supra* note 2 at 13.

[59] Zhang et al, *supra* note 41 at 2331.

[60] Duan-yang Yuan et al, "Effects of water exchange rate on morphological and physiological characteristics of two submerged macrophytes from Erhai Lake" (2017) 8 Ecology & Evolution 12750 at 12750.

[61] Carr, Duthie, & Taylor, *supra* note 6 at 195; Mark D. Sytsma & Lars W. J. Anderson, "Nutrient Limitation in *Myriophyllum Aquaticum*" (1993) 8:2 Journal of Freshwater Ecology 165 at 165; J.R. Webstead & E.F. Benfield, "Vascular Plant Breakdown in Freshwater Ecosystems" (1986) 17 Annual Review of Ecological Systems 567 at 572.

[62] Wetzel, *supra* note 5 at 187, 235, 254.

production of allelochemicals.[63] N and P are "most bioavailable in their dissolved inorganic forms, phosphate, nitrate, and ammonium".[64]

Preikshot notes Somenos Creek's eutrophic conditions, as well as positive correlation between PF's "rapid growth" and the "superabundance" of Nitrogen (N) and Phosphorous (P) in Somenos Creek.[65] The increase in plant biomass production due to increase in nutrient supply is called "eutrophication".[66]

Increases in nutrient availability from runoff associated with development activities, or nutrient leaching from collection of detritus under low oxygen conditions, render ecosystems "more susceptible to invasion". [67] As such, a growth strategy with high resource use efficiency, and plasticity in biomass allocation, "elevate the likelihood" of negative impacts upon introduction to an aquatic community.[68] Indeed, in laboratory studies of heterogeneous spatial distribution of sediment nutrients, PF can allocate greater biomass to shoots and roots to search for nutrients at the expense of floating biomass.[69]

a. Nitrogen and Phosphorus

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[63] Bart M. C. Grutters et al, "Growth strategy, phylogeny and stoichiometry determine the allelopathic potential of native and non-native plants" (2017) 126 Oikos 1770.

[64] Christopher A. Mebane, Nancy S. Simon, & Terry R. Maret, "Linking nutrient enrichment and streamflow to macrophytes in agricultural streams" (2014) 722 Hydrobiologia 143 at 153.

[65] Preikshot, *supra* note 2 at 23.

[66] *Ibid* at 14; Olga Babourina & Zed Rengel, "Nitrogen Removal from Eutrophicated Water by Aquatic Plants" in Abid A. Ansari et al, eds, *Eutrophication: causes, consequences and control* (Springer, 2011) 355; See Carr, Duthie, & Taylor, *supra* note 6 at 198.

[67] Tong Wang et al, "Pervasive native plant has the potential to resist the invasion of exotic species: a trait-based comparison" (2023) 850 Hydrobiologia 2015 at 2016-17.

[68] Kuehne, Olden & Rubenson, *supra* note 1 at 1846.

[69] Nan Shen et al, "Does Soil Nutrient Heterogeneity Improve the Growth Performance and Intraspecific Competition of the Invasive Plant *Myriophyllum aquaticum*?" (2019) 10:723 Frontiers in Plant Science 1.

Nutrient and CO2 limiting conditions affect PF's phenotypic growth response.[70] With decreasing nutrient availability, root to shoot ratio increases.[71]

During summer growing season, rhizomes accumulate N concentration, containing 42-89% of total N, but not P. Rhizomes contained "only 3%" of total P.[72] On the other hand, emergent growth stems contained 80% of P, with decreasing N concentration from June to September.[73] As such, the authors found that PF relies on "current uptake of P" from sediment and water column for growth rather than storage mechanisms.[74]

In other studies, PF can utilize ammonia (NH4+) and nitrate (NO3) introduced through wastewater and agricultural runoff.[75] In response to waters loaded with other nutrient forms of N, PF demonstrates adaptive regulatory metabolism. PF resists similar ammonia toxicity in lab conditions.[76]

PF can also adapt to P stress at elevated or low levels, in regulating photosynthetic pathways and oxidative stress response.[77] In particular, low phosphorous stress exerts a greater impact on biomass growth than high phosphorous stress.[78]

A study conducted at Snake River Basin, Idaho examined "whether nutrients, streamflow, or other environmental variables best explained macrophyte abundance in streams in an

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[70] Gufu, Manea, Leishman, *supra* note 57 at 3488.

[71] *Ibid*; Thiébaut & Martinez, *supra* note 34 at 192-94.

[72] Sytsma & Andersen, "Biomass, Nitrogen, and Phosphorus", *supra* note 19 at 244.

[73] *Ibid*.

[74] *Ibid*.

[75] Rui Wang et al, "The adaptability of a wetland plant species *Myriophyllum aquaticum* to different nitrogen forms and nitrogen removal efficiency in constructed wetlands" (2018) 25 Environmental Science and Pollution Research 7785.

[76] Rui Wang et al, "Complex regulatory network allows *Myriophyllum aquaticum* to thrive under high-concentration ammonia toxicity" (2019) 9:4801 Scientific Reports 1 at 1.

[77] Cancan Jiang et al, "Transcriptomics Insights into Phosphorus Stress Response of *Myriophyllum aquaticum*" (2023) 24:4874 Int. J Mol. Sci. 1.

[78] *Ibid* at 8-9.

agriculturally dominated landscape".[79] Nitrogen in sediment and the water column were positively correlated with macrophyte biomass.[80] P levels in sediment were also positively correlated with biomass.[81] P levels in the water column were the only nutrient that did not limit PF's growth, suggesting greater significance of P uptake from sediment.[82]

In a laboratory study investigating the relative importance of sediment versus water column nutrient uptake, roots facilitate N and P uptake when nutrient loading is greater in sediment than the water column.[83] Accordingly in another study, the mass flow of sediment nutrients into the water column did not exhibit significant nutrient supply to roots.[84]

In Somenos Creek, elevated phosphorous levels are observed where PF is most abundant. Richards Creek as tributary stream contains high P associated with agricultural run-off, yet no PF is present (See Table 1 below). Given PF's observed reliance on current uptake of P rather than storage, as well as greater stress from low P, PF's absence at Richard's Creek may suggest introduction of PF at a lower point in Somenos Basin's conveyance system of water, either Somenos Lake or Somenos Creek.

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[79] Mebane, Simon, & Maret, *supra* note 64 at 143.
[80] *Ibid*.
[81] *Ibid*.
[82] *Ibid*.
[83] Tan et al, *supra* note 11 at 5.
[84] Sytsma & Anderson, "Transpiration", *supra* note 11 at 98.

Table 1: Water Quality Data in Somenos Basin (May/July, 2024)

Place	Date	Phosphate (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	BC Provincial Guideline (mg/L)[85]
Head of Somenos Creek (Near Somenos Lake)	July 25, 2024	0.48	0.002	0	Hyper-eutrophic in Phosphorus (>0.1)
Head of Somenos Creek (Near Beginning of Creek)	July 25, 2024	0.30	0	0	Hyper-eutrophic in Phosphorus (>0.1)
Somenos Creek @ Lakes Road	May 7, 2024	0.39	0.003	0	Hyper-eutrophic in Phosphorus (>0.1)
Richards Creek @ Herd Road	May 7, 2024	0.33	0.003	0	Hyper-eutrophic in

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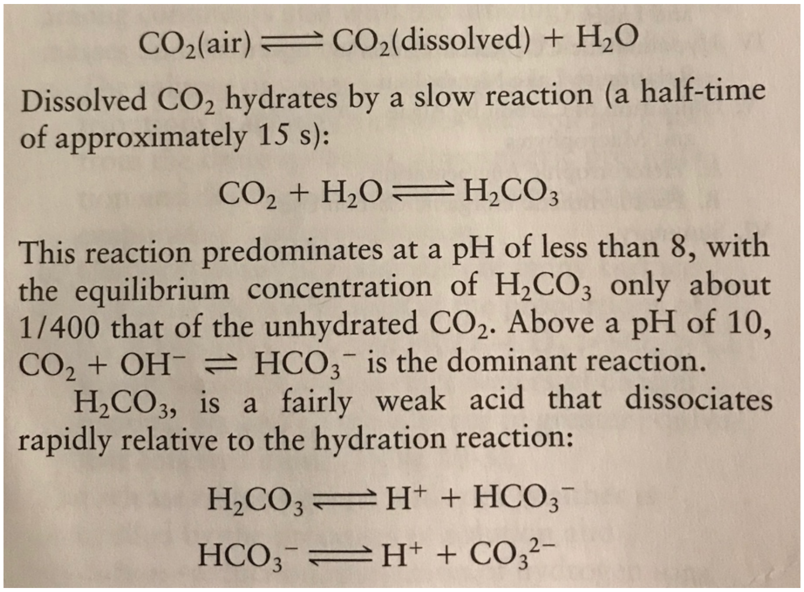
[85] Canadian Council of Ministers of the Environment, "Canadian water quality guidelines for the protection of aquatic life: Phosphorus" (2004) Canadian Guidance Framework for the Management of Freshwater Systems 1 at 4.

					Phosphorus (>0.1)

b. Carbon and Light

CO2 availability in the water column is limited by its ability to diffuse across water and air, and its dissociation in carbonate forms.[86] The equilibria of gaseous CO2's rate of diffusion and evaporation across the air and water surface, alongside reduction and oxidation of water-soluble carbonate forms, determines the availability of inorganic carbon for photosynthesis (See Figure 2 below, reproduced from Wetzel, pg. 188).[87]



$$CO_2(\text{air}) \rightleftharpoons CO_2(\text{dissolved}) + H_2O$$

Dissolved CO_2 hydrates by a slow reaction (a half-time of approximately 15 s):

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

This reaction predominates at a pH of less than 8, with the equilibrium concentration of H_2CO_3 only about 1/400 that of the unhydrated CO_2. Above a pH of 10, $CO_2 + OH^- \rightleftharpoons HCO_3^-$ is the dominant reaction.

H_2CO_3, is a fairly weak acid that dissociates rapidly relative to the hydration reaction:

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$$

Figure 2: Diffusion and Dissociation of CO2 in Water (Wetzel, pg. 188).

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[86] Malheiro, Jahns, & Hussner, *supra* note 9 at 31.

[87] Wetzel, *supra* note 5 at 188-89.

The availability and consumption of CO2 and HCO3 in relation to pH is a "major factor determining the distribution of submerged species in aquatic habitats" and in mediating the growth of PF.[88] In laboratory studies examining high CO2 conditions, PF allocates greater biomass to roots relative to leaves.[89]

Phenotypic change in growth form is a function of carbon and light availability, observed in experimental conditions.[90] In limited light conditions, PF increases shoot ("emergent stolon") length "to overcome change in light availability and to invade different habitats.[91] Empirical support from Somenos Marsh Wildlife Society's "smothering trial experiment" demonstrate this growth adaptation. Pond liner was placed "on top of the creek in the summer to smother the above-water growth of Parrot's feather".[92] However, results revealed PF's ability to grow from under the sides and overtop the liner, "cover[ing] most of it".[93]

In addition to structural phenotypic plasticity in relation to CO2 availability, submerged growth forms of PF can utilize HCO3 in self-regulating carbon storage and metabolism with changing conditions.[94] However, compared to 7 other *Myriophyllum* species, PF's regulatory adaptation is not as sophisticated.[95]

C. PF Allelopathy and Interaction with Other Aquatic Plants

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[88] Malheiro, Jahns, & Hussner, *supra* note 9 at 31.
[89] Emin Dülger & Andreas Hussner, "Differences in the growth and physiological response of eight *Myriophyllum* species to carbon dioxide depletion" (2017) 139 Aquatic Botany 25.
[90] Malheiro, Jahns, Hussner, *supra* note 9 at 35.
[91] Ryan M. Wersal & John D. Madsen, "Influences of light intensity variations on growth characteristics of *Myriophyllum aquaticum*" (2013) 28:2 Journal of Freshwater Ecology 147.
[92] Gina Hoar & Adam Dewar, "Parrot's Feather Management: Report of Activities & Survey 2021" (2021) Somenos Marsh Wildlife Society 1 at 2.
[93] *Ibid* at 4.
[94] Malheiro, Jahns & Hussner, *supra* note 9 at 31; See Erhard, *supra* note 10 at 433-34.
[95] Dülger & Hussner, *supra* note 89 at 25.

Aquatic plants can reduce growth of competitor species by releasing allelochemicals.[96] As such, allelopathy typically refers to the inhibitory effect of chemicals released by plants on growth of competitor species,[97] but can also describe stimulatory effects on neighbouring aquatic plants.[98] Allelopathic potential is highly correlated with higher Carbon:Phosphorus (C:P) ratios, reflecting "enhanced allocation of carbon to phenolic compounds". [99] In a study of allelopathic potential of sixteen aquatic plants in Brazil, PF produced the second-most phenolic compounds.[100] Production of allelochemicals is also limited by carbon and nutrient availability.[101] C:P ratios are especially high in invasive plants requiring greater carbon for mat-like structural biomass.[102]

Phenolic compounds like tannins are composed of "one or more hydroxyl groups attached to one or more aromatic carbon rings".[103] As such, phenotypic plasticity like PF's emergent and submerged growth forms exhibit variation in phenolic compounds, especially dependent on N, P, or C.[104] For example, emergent growth forms "contain more phenolics than submerged plant species".[105]

The chemical composition of allelochemicals is directly related to phylogeny and growth strategy.[106] The production of allelochemicals by aquatic plants "may have evolved to suppress

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[96] Grutters et al, *supra* note 63 at 1770.
[97] Ole Pedersen, "Allelopathy – Chemical Warfare Between Aquatic Plants" (2002) 15 The Aquatic Gardener 9.
[98] Gabrielle Thiébaut, Michèle Tarayre & Héctor Rodríguez-Pérez, "Allelopathic Effects of Native Versus Invasive Plants on One Major Invader" (2019) 10:854 Frontiers in Plant Science 1.
[99] Grutters et al, *supra* note 63 at 1776.
[100] Gisela Mayora, Berenice Schneider, & María Florencia Gutierrez, "Phenolic Content of Aquatic Macrophytes of the Middle Paraná River Floodplain" (2022) 42:54 Wetlands 1 at 8.
[101] Grutters et al, *supra* note 63 at 1775.
[102] *Ibid* at 1776.
[103] Mayora, Schneider, & Gutierrez, *supra* note 100 at 1.
[104] Grutters et al, *supra* note 63 at 1770-71.
[105] *Ibid* at 1770.
[106] Grutters et al, *supra* note 63 at 1770.

or even kill their neighbours, thus eliminating the competition for limited resources".[107] Two theories explain the observed function of allelopathic chemicals on neighbouring aquatic plants by invasive species.[108]

The Novel Weapon Hypothesis proposes that the geographic origin of certain plant species influences magnitude of inhibitory effect on plants outside their "native range". [109] As a newly introduced "weapon", allelochemicals offer a competitive advantage in negotiating space for uptake of nutrients.

On the other hand, the Biotic Resistance explanation considers resistance to invasion due to functional similarity between invasive and native plants with respect to resource competition.[110] As such, plants with similar functions, growth strategies, and metabolic adaptations as invading species may better resist invasion, including allelochemicals.[111] Co-evolution of plant species may favour resistance to inhibitory effects, or in some cases mutually facilitate growth.[112] Alternatively, neighbouring aquatic plants with a "long co-evolutionary history" may exert little impact on each other through allelochemicals.[113] On the other hand, plant species with a recent history of exposure "may exhibit less resistance" to allelopathic effects by invasive species.[114]

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[107] Takudzwa C. Madzivanzira, Julie A. Coetzee, & Tatenda Dalu, "Factors Structuring Aquatic Macrophytes" in Sanjeev Kumar et al, eds, *Aquatic Macrophytes: Ecology, Functions and Services* (Springer Nature, 2023) 21 at 27.

[108] Thiébaut, Tarayre & Rodríguez-Pérez, *supra* note 98 at 2.

[109] Jonathan P. Fleming & Eric D. Dibble, "Ecological mechanisms of invasion success in aquatic macrophytes" (2015) 746 Hydrobiologia 23 at 28.

[110] Wang et al, *supra* note 67 at 2015; F. A. Yannelli et al, "Limiting similarity and Darwin's naturalization hypothesis: understanding the drivers of biotic resistance against invasive plant species" (2017) 183 Oecologia 775.

[111] Wang et al, *supra* note 67 at 2016.

[112] Thiébaut, Tarayre, & Rodríguez-Pérez, *supra* note 98 at 2.

[113] Madzivanzira, Coetzee, & Dalu, *supra* note 107 at 27.

[114] Thiébaut, Tarayre, & Rodríguez-Pérez, *supra* note 98 at 2.

For example, PF can facilitate the growth of other invasive plants, like the water primrose,[115] or V. spinulosa,[116] demonstrated in laboratory experiments. Yet in other laboratory experiments, water lily and PF inhibited growth of common duckweed species.[117]

Observation of competition and growth distribution are ongoing in Somenos Creek.[118] Documented in Fall and Summer of 2022, Smartweed (*Persicaria maculosa*) appears to grow within PF's mat structure, "diluting it's percent area, but still creating dense mats".[119] This could indicate potential positive allelopathic effects from one plant to another.[120] However, it could also indicate no mutual effect from similar competitive functions, or mutual growth benefit unrelated to allelopathy in sharing a mat structure scaffold on the water surface.[121] On the other hand, Yellow Pond Lily (*Nuphar polysepala*) can outcompete PF in areas pre-established, showing resistance to invasion.[122]

The next section investigates the growth mechanisms of these plants. As will be discussed after, understanding growth and reproduction of these plants in relation to PF, sheds light on their interaction at headwaters and intermediate sections of Somenos Creek.

i) Yellow Pond Lily

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[115] *Ibid* at 8.
[116] Guixiang Yuan et al, "How Eutrophication Promotes Exotic Aquatic Plant Invasion in the Lake Littoral Zone?" (2023) 57 Environmental Science & Technology 8002 at 8007-08.
[117] Stella D. Elakovich & Jean W. Wooten, "Allelopathic Potential of Sixteen Aquatic and Wetland Plants" (1989) 27 Journal of Aquatic Plant Management 78 at 82.
[118] Hoar, "Late Summer – Fall 2022: Parrot's Feather Update", *supra* note 22 at 3; See also Preikshot, *supra* note 2 at 13.
[119] Hoar, "Late Summer – Fall 2022: Parrot's Feather Update", *supra* note 22 at 3.
[120] *Ibid*.
[121] Katja Klančnik et al, "The quality and quantity of light in the water column are altered by the optical properties of natant plant species" (2018) 812 Hydrobiologia 203 at 203-04; See Thiébaut & Martinez, *supra* note 34 at 183.
[122] Hoar, "Late Summer – Fall 2022: Parrot's Feather Update", *supra* note 22 at 3.

Yellow Pond Lily (*Nymphaeaceae* family, *Nuphar* genus) originates broadly from the Northern Hemisphere, "with a Euro-Western-Asia temperate range", including British Columbia.[123] In Somenos Creek, *Nuphar polysepala* and *Nuphar lutea* are observed.[124] The *polysepala* species is distinct from the *lutea* species, where the former "often lacks submersed leaves" but emerges from the water surface as the largest standing lotus in the *Nuphar* genus (See Figure 3 below).[125]

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[123] O. A. Lebedeva, E. A. Belyakov, & A.G. Lapirov, "Reproductive potential of yellow water-lily (*Nuphar* lutea) in the conditions of lake ecosystems" (2020) 28:1 Biosystems Diversity 60.
[124] Hoar, "Late Summer – Fall 2022: Parrot's Feather Update", *supra* note 22 at 1; Rasmussen, *supra* note 37 at 17.
[125] Donald H. Les, *Aquatic Dicotyledons of North America: Ecology, Life History, and Systematics* (CRC Press, 2018) at 15.

Figure 3: *Nuphar Polysepala* in Somenos Creek (July 10, 2024).

Nuphar distribution depends on seed floating ability for dispersion.[126] Yellow Pond Lily's preference for low hydrodynamic environments, allow it to "easily inhabit new habitats where it can spontaneously disperse or reproduce".[127] Its reproductive strategy involves prolonged germination, allowing "seeds to grow in portions and over an extended period of time".[128] This adaptation to drought and flooding,[129] promotes accumulation of "generative diaspores in the soil".[130] It is also known to exert allelopathic effect on neighbouring plants and microorganisms, like blue-green cyanobacteria and zooplankton.[131]

Indeed, species of Yellow Pond Lily release allelochemicals like alkaloids and phenols.[132] For example, *Nuphar lutea* releases the phosphorus-dependent phenol, resorcinol, inhibiting zooplankton and common duckweed growth.[133] Further, *Nuphar lutea* releases the alkaloid, 6,6'-dihydroxythiobinupharidine, partly composed of N.[134] Notably, resorcinol is inversely correlated with nitrate levels and light supply, suggesting influence in competition over N.[135]

ii) Smartweed

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[126] Ibid.
[127] Lebedeva, Belyakov, & Lapirov, *supra* note 123 at 60.
[128] Ibid at 66.
[129] Ibid at 60, 66.
[130] Ibid at 60.
[131] Inna Nezbrytska et al, "Potential Use of Aquatic Vascular Plants to Control Cyanobacterial Blooms: A Review" (2022) 14 Water 1727; Rainer Sütfeld, Frank Petereit, & Adolf Nahrstedt, "Resorcinol in Exudates of *Nuphar lutea*" (1996) 22:12 Journal of Chemical Ecology 2221.
[132] Stella D. Elakovich, Stacey Spence, & Jie Yang, "Phytochemical Inhibitors from the *Nymphaeaceae*: *Nymphaea odorata* and *Nuphar lutea*" in Horace G. Cutler & Stephen J. Cutler, eds, *Biologically Active Natural Products: Agrochemicals* (CRC Press, 1999) 49; Stella D. Elakovich & Jean W. Wooten, "Allelopathic Potential of *Nuphar lutea* Sibth. & Sm. (Nymphaeaceae)" (1991) 17:4 Journal of Chemical Ecology 707; See also Preikshot, *supra* note 2 at 12.
[133] Erhard, *supra* note 10 at 437; Sütfeld, Petereit, & Nahrstedt, *supra* note 131 at 2221.
[134] Elakovich, Spence, & Yang, *supra* note 132 at 52.
[135] Sütfeld, Petereit, & Nahrstedt, *supra* note 131 at 2224-25.

Allelopathy studies on *Polygonum maculosa* ("formerly named *Polygonum persicaria"*),[136] examine its capacity to be affected by allelochemicals rather than as producer.[137] For example, agricultural pea crop suppress "germination and growth" of Smartweed.[138] However, the broader *Polygonum* genus is known to produce allelochemicals.[139]

Smartweed's reproductive strategy involves "transgenerational plasticity", where maternal environments influence growth adaptations in offspring.[140] For example, "drought-stressed" Smartweed will produce offspring "with longer roots and greater biomass when grown in dry conditions".[141] Under drought conditions, Smartweed also exhibits water use efficiency.[142]

Smartweed can sexually reproduce across a range of moisture gradients from dry to flooded,[143] albeit when studied under lab conditions, with "significantly low average fitness".[144] Similar to Yellow Pond Lily, Smartweed's adaptation to water stress may explain observed

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[136] A. Zohry & S. Ouda, "Crop Rotation Defeats Pests and Weeds" in Samiha Ouda, Abd El-Hafeez Zohry, & Thany Noreldin, eds, *Crop Rotation: An Approach to Secure Future Food* (Springer Nature, 2018) 77 at 80.

[137] R. J. Willis, *The History of Allelopathy* (Springer, 2007) at 270.

[138] Chandan Das, Avishek Dey, & Abhjit Bandyopadhyay, "Allelochemicals: An Emerging Tool for Weed Management" in Subhash C. Mandal, Raja Chakraborty, Saikat Sen, eds, *Evidence Based Validation of Traditional Medicines: A Comprehensive Approach* (Springer Nature, 2006) 249 at 255; Dorota Soltys et al, "Allelochemicals as Bioherbicides – Present and Perspectives" in Andrew J. Price & Jessica A. Kelton, *Herbicides – Current Research and Case Studies in Use* (IntechOpen, 2013) at 523.

[139] Klančnik et al, *supra* note 121 at 204; Evgeny Kurashov et al, "The Use of Fluorescence Microscopy to Assess the Suppression of the Development of Cyanobacteria under the Influence of Allelochemicals of Aquatic Macrophytes" in Natalia Grigoryeva, ed, *Fluorescence Methods for Investigation of Living Cells and Microorganisms* (InTechOpen, 2020) 1 at 3-5.

[140] Silvia Matesanz, Ernesto Gianoli, & Fernando Valladares, "Global change and the evolution of phenotypic plasticity in plants" (2010) 1206 Annals of the New York Academy of Sciences 35 at 41.

[141] *Ibid* at 41.

[142] *Ibid* at 39.

[143] Julie K. Cronk & M. Siobhan Fennessy, *Wetland Plants: Biology and Ecology* (CRC Press, 2001) at 271. Three other *Polygonum* species exhibit flooding tolerance: See Mark F. Carter & James B. Grace, "Relationships Between Flooding Tolerance, Life History, and Short-Term Competitive Performance in Three Species of *Polygonum*" (1990) 77:3 American Journal of Botany 381.

[144] S.E. Sultan & F. A. Bazzaz, "Phenotypic Plasticity in *Polygonum Persicaria* II. Norms of Reaction to Soil Moisture and the Maintenance of Genetic Diversity" (1993) 47:4 Evolution 1032 at 1044-1045.

"priority effects", where initial occupation secures potential to reproduce against invaders.[145] Much like PF, Smartweed makes use of "extensive dense mats [in] competition for efficient use of resources", which may mutually benefit PF.[146]

iii) Presence/Absence at Headwaters and Intermediate Sections of Creek

PF's growth distribution in Somenos Creek has moved downstream, with no growth at headwaters near Somenos Lake.[147]

The disappearance of PF growth at headwaters is puzzling, given lack of tree canopy shading and exposure to sunlight. As well, water depth is not a significant factor according to fieldwork data.

Consider that at mid-creek, near Lakes Road, water depth is about 1.5m with abundant PF growth (See Table 1 above).[148] On the other hand, at the head of Somenos Creek, the edge area near Somenos Lake has a depth of 2m with no PF. Towards the beginning of the creek, begins a slight decrease in depth to about 1.8m, still with no PF. This slight change in gradient is well within the 2m limit for PF root establishment and light access.

However, Pond Lillies overtake this headwaters area, forming large emergent leaf canopies (See Figure 4 below).

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[145] James E. Moore & Scott B. Franklin, "Water stress interacts with early arrival to influence interspecific and intraspecific priority competition: a test using a greenhouse study" (2012) 23 Journal of Vegetation Science 647 at 652.

[146] Klančnik et al, *supra* note 121 at 204.

[147] Kuehne et al, *supra* note 31 at 899. Across the 20-year period on the Chehalis River in Washington, USA, PF distribution moved downstream, with a concentration at intermediate sections. Dominant sections of PF growth were relatively smaller with "uniformly shallow depth and low bank slopes".

[148] Hoar, "Late Summer – Fall 2022: Parrot's Feather Update", *supra* note 22 at 4.

Figure 4: Yellow Pond Lily Growth at Somenos Creek headwaters, facing Somenos Lake (July 10, 2024).

Shading from leaf canopy may play a factor, in addition to potential allelopathic effects. Pond Lillies' earlier arrival, longstanding accumulation of sediment diaspores, and similar resistance to water stress, may also explain PF's failed establishment. At intermediate sections of Somenos Creek near Lakes Road, Pond Lillies and PF grow separated on opposite sides (See Figure 5 below). Separation could indicate mutual inhibitory effects.

Figure 6: Separation of Pond Lily and PF/Smartweed near Lakes Road, Somenos Creek, facing toward headwaters (July 25, 2024).

At intermediate sections of the Creek, Smartweed grows within PF's mat structure, observed in past and recent fieldwork (See Figure 6 below).[149]

Figure 6: Smartweed Growth interlaced with PF (July 10, 2024).

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[149] Hoar, "Late Summer – Fall 2022: Parrot's Feather Update", *supra* note 22 at 4.

Much like PF and Pond Lily, Smartweed tolerates periods of drought or flooding. However, like PF, it shares a similar mat structure in competition for sunlight.[150] Sharing a mat structure may reduce carbon consumption required to maintain floating structural biomass.[151]

4) Conclusion

PF's phenotypic plasticity in growth form and nutrient metabolism provide advantages in competition over space and aquatic resources. Yellow Pond Lily and Smartweed resist invasion in distinct ways, with the former negotiating separate space, and the latter growing in proximity. PF's allelopathic effects may be ineffective against Yellow Pond Lily at headwaters, given Pond Lily's potentially high number of seasonal diaspores in sediment. Separation at intermediate areas of Somenos Creek may indicate mutual inhibitory effects. On the other hand, mutual benefit unrelated to allelopathy may be responsible for Smartweed's ability to grow near and within PF's mat structure.

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[150] Klančnik et al, *supra* note 121 at 203-04.
[151] *Ibid*; See Thiébaut & Martinez, *supra* note 34 at 183; Grutters et al, *supra* note 63 at 1776.

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