Experimental evolution reveals adaptive limits and evolutionary dynamics of freshwater photoautotrophs under environmental stress

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Background

- **Freshwater cyanobacteria and microalgae are key primary producers** whose persistence is increasingly challenged by rapid environmental change.
- **Stressors** such as salinity, temperature shifts and herbicides conditions **impose strong selective pressures on microbial populations.**

Research questions:

- *How does the rate of environmental deterioration shape the adaptive capacity of freshwater cyanobacteria and microalgae?*
- *what ecological and physiological costs emerge as populations evolve resistance to increasing stress?*

Methodology

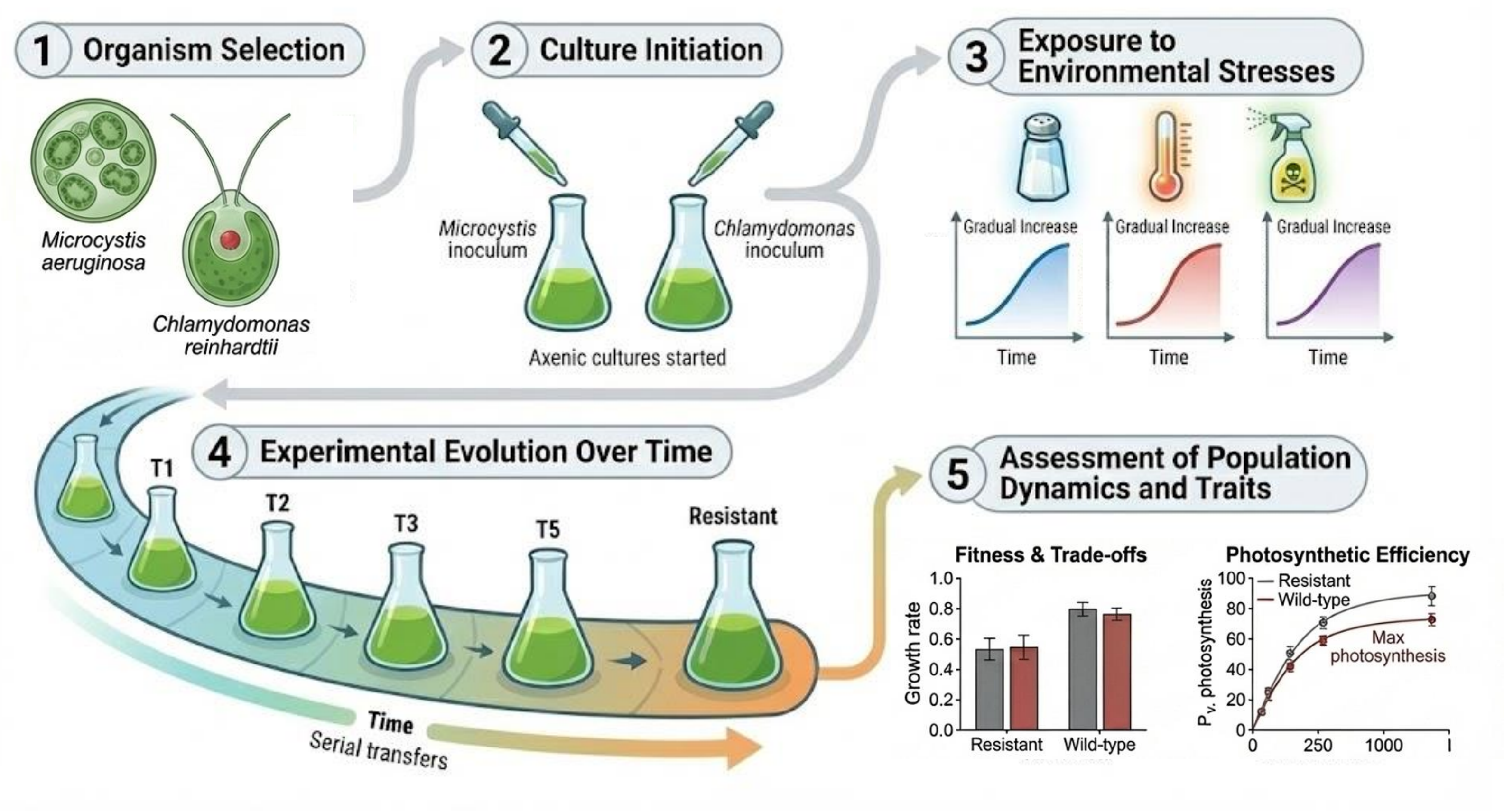

Figure 1. Experimental evolution workflow for freshwater photoautotrophs. The scheme outlines the five methodological phases: **(1-2)** Selection of *Microcystis aeruginosa* and *Chlamydomonas reinhardtii* and culture initiation. **(3)** Exposure to environmental stressors using gradual increase regimes. **(4)** Serial transfers over multiple generations to select for resistance. **(5)** Final assessment of population dynamics, comparing fitness, trade-offs, and photosynthetic efficiency between resistant and wild-type strains.

Freshwater phytoplankton could adapt to lethal levels herbicides due to rapid evolutionary processes

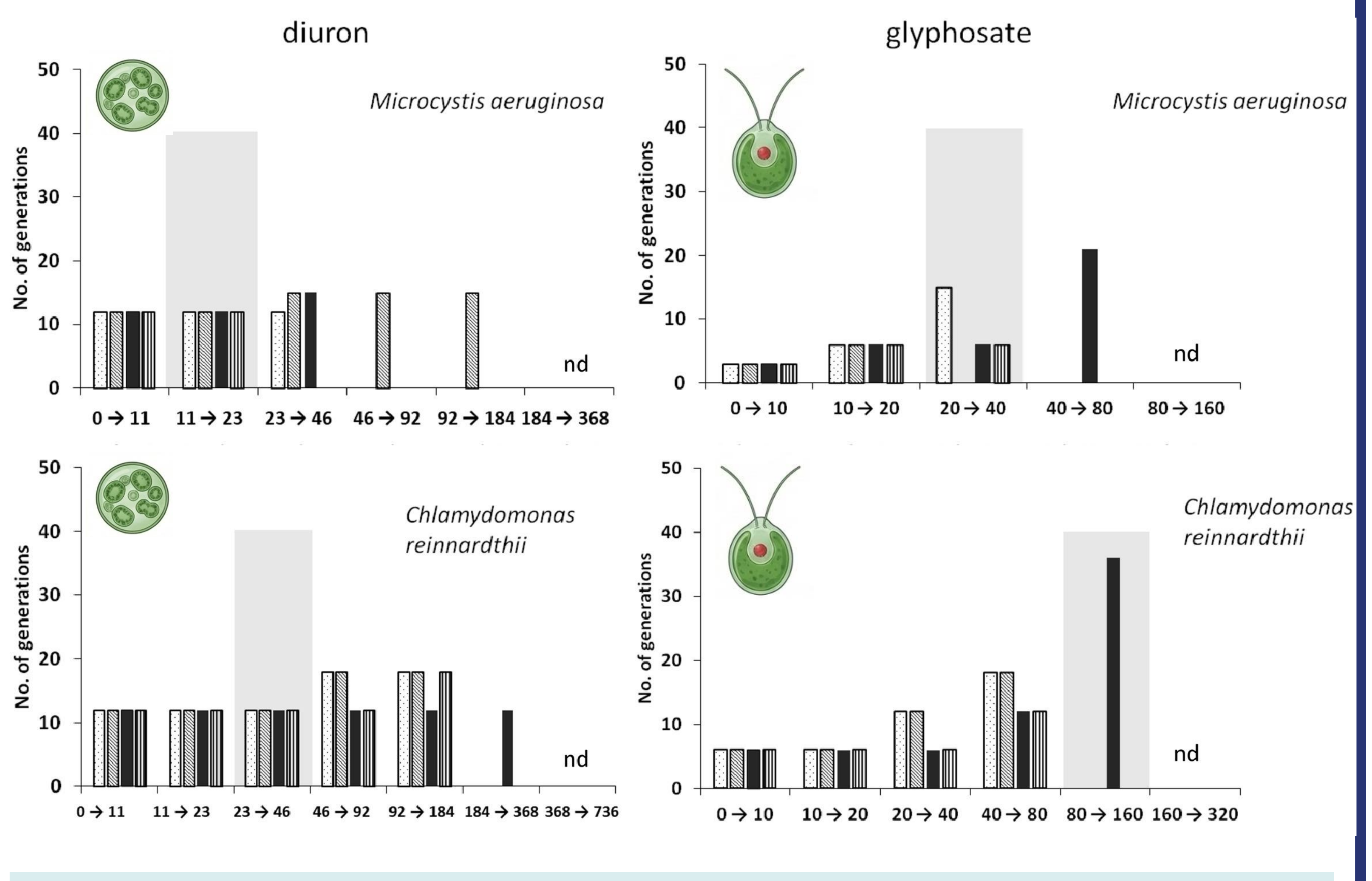

Figure 2. Number of generations required to grow under increasing doses of diuron and glyphosate during the ratchet experiment. Four independent cultures (represented by different column patterns) were tested per each herbicide and species. The ratchet experiment was finished when growth was not observed in any of the four replicates tested (designated 'nd', non-detectable growth). Grey shading over a ratchet cycle indicates that the concentration tested equalled or surpassed the initial lethal dose for each herbicide and species.

The rate of change determinates the level of resistance

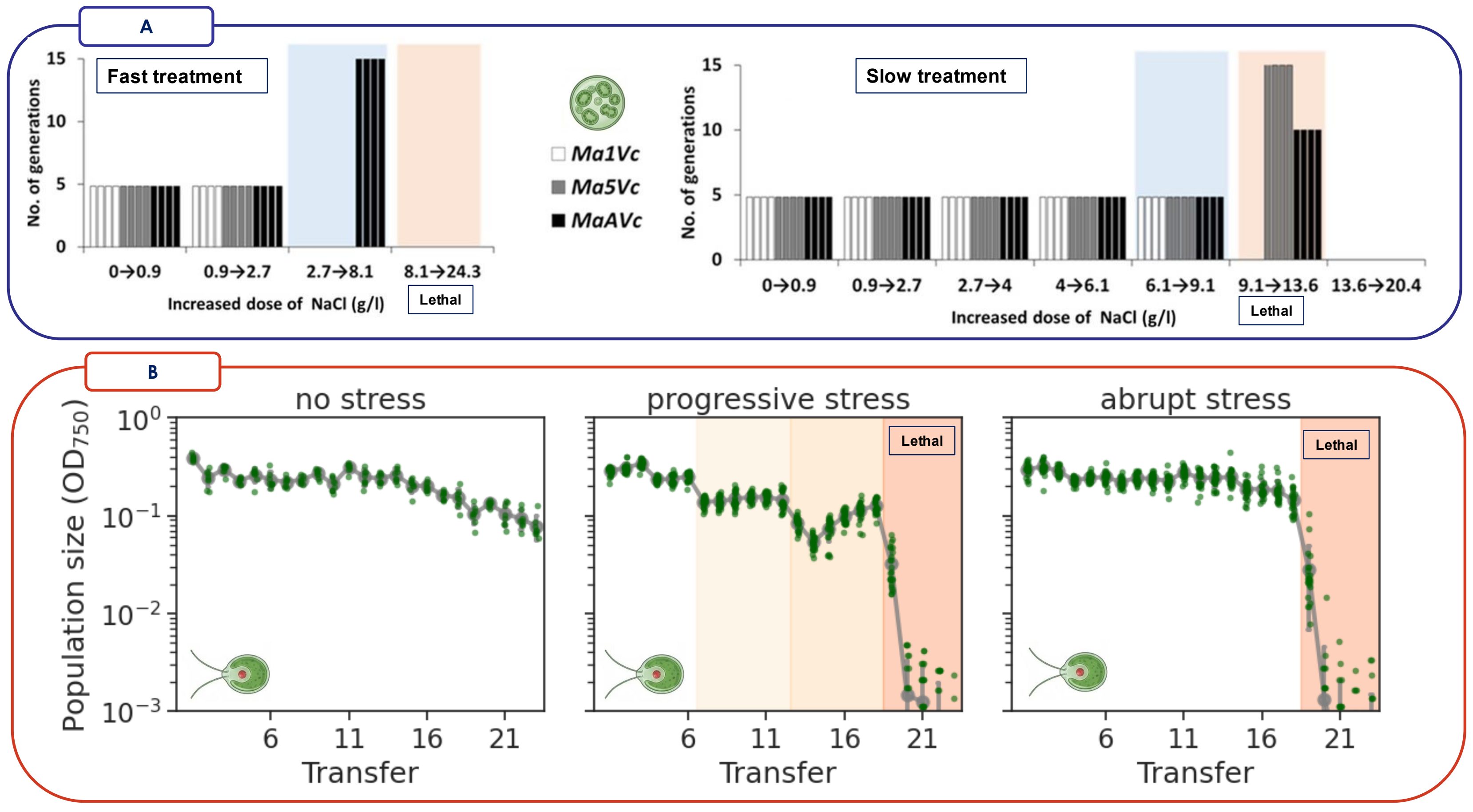

Fig. 3. Evolutionary dynamics under gradually imposed environmental stress. (A) *Ratchet* experiment in *Microcystis aeruginosa*, where independent populations are exposed to stepwise increases in salinity (NaCl). **(B)** Gradual temperature-increase experiment in *Chlamydomonas reinhardtii*, in which populations are successively transferred to slightly higher temperatures. Population size dynamics across experimental transfers capture the evolutionary response to continuously increasing thermal stress.

Resistant cells showed drastic alterations of photosynthetic performance

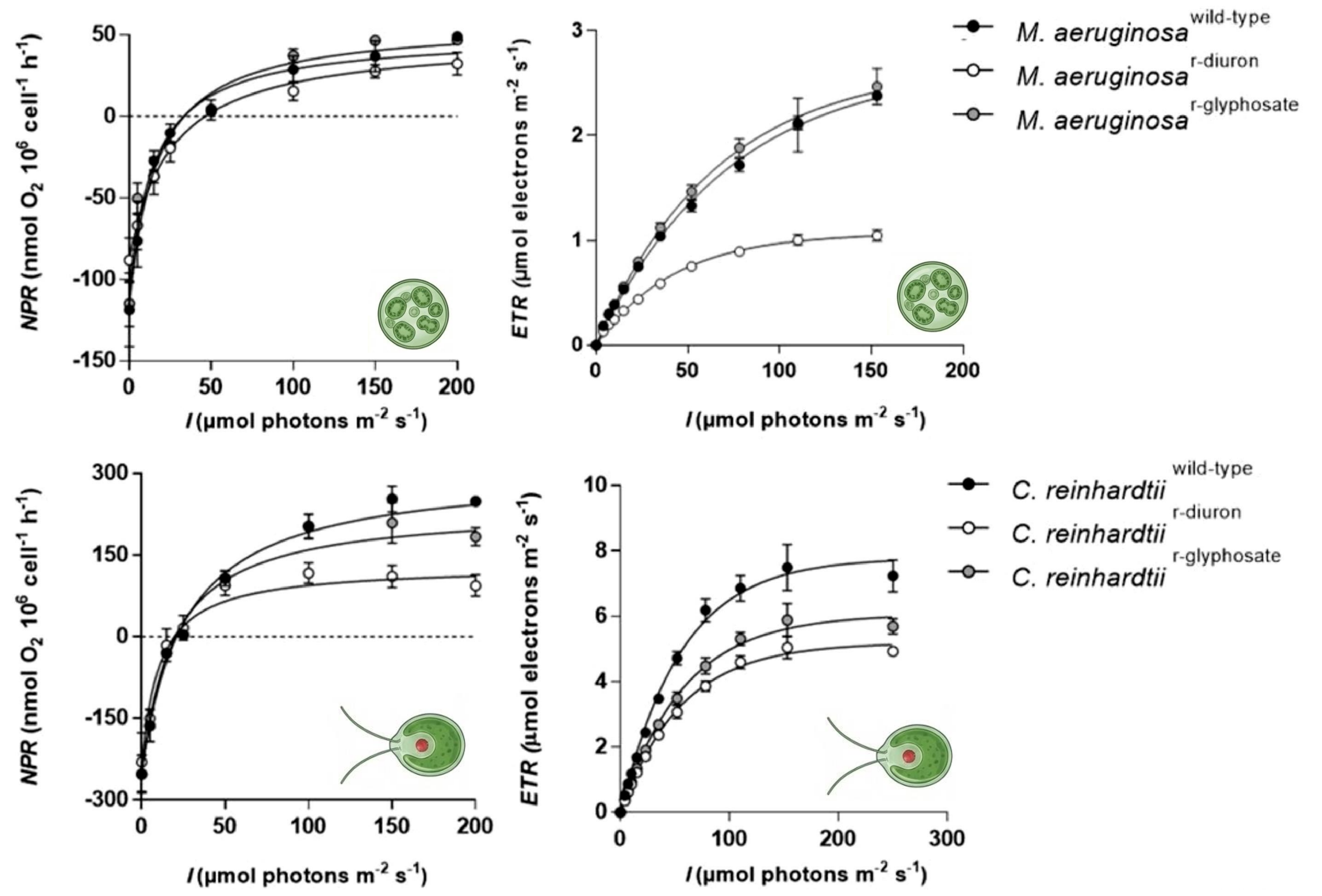

Fig. 4. Net photosynthetic rate (*NPR*) and electron transport rate (*ETR*) at increasing irradiances (*I*) of the wild-type and herbicide-resistant strains of each species. Data are mean ± SD (n=4).

Conclusions

1. Adaptation to rapidly changing environmental stressors was consistently observed, but substantial physiological costs, including marked reductions in photosynthetic efficiency and growth rates.

2. These trade-offs indicate that increased stress tolerance does not equate to maintain ecosystem function, even when populations are able to persist.

3. Rapid evolutionary responses in freshwater phototrophs may buffer short-term survival while simultaneously undermining long-term productivity and food-web stability.

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