Ecological Indicators 30 (2013) 16–20

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Short communication

Fall synchrony between leaf color change and brook trout spawning in the Laurentides Wildlife Reserve (Québec, Canada) as potential environmental integrators

Marc Pépino*, Raphaël Proulx, Pierre Magnan

Centre de Recherche sur les Interactions Bassins Versants – Écosystèmes Aquatiques (RIVE), and Groupe de Recherche Interuniversitaire en Limnologie et en Environnement Aquatique (GRIL), Université du Québec à Trois-Rivières, C.P. 500, Trois-Rivières, Québec, G9A 5H7 Canada

ARTICLE INFO

Article history:
Received 10 December 2012
Received in revised form 28 January 2013
Accepted 30 January 2013

Keywords:
Color indices
Digital images
Monitoring program
Fall phenology
Seasonal timing
Synchrony

ABSTRACT

Fall biological processes are driven by a combination of environmental factors, with cumulative effects over the length of the growing season, which are currently difficult to model. This study evaluated if leaf color change in fall (i.e., leaf yellowing) and brook trout spawning could be two biological processes that are synchronized at a regional scale and if leaf yellowing could be used to determine the peak of spawning activity of this species. To this end, we surveyed 551 brook trout redds and examined 193 digital images of forest trees in the Laurentides Wildlife Reserve (Québec, Canada) over the fall season. Results showed that leaf yellowing and brook trout spawning were synchronized, providing one of the first examples of temporal matching between freshwater and terrestrial biological processes at the regional scale. Considering the difficulty of monitoring the phenology of freshwater fish spawning at high spatial and temporal resolution, terrestrial integrators of environmental conditions, such as leaf color change, may prove to be promising predictors of spawning activity in the management of fish populations.

1. Introduction

According to Lechowicz (2001), “phenology is the study of the seasonal timing of events in nature: when flowers bloom, trees leaf out, birds migrate, animals hibernate, fish spawn, phytoplankton blooms, lakes freeze and the like.” Unfortunately, the limitations of current monitoring programs make it difficult to study the phenology of individual species at high spatial and temporal resolution (Miller-Rushing et al., 2010; Morisette et al., 2009), and phenological observations of freshwater organisms are particularly scarce (Parmesan, 2007).

Temperature and photoperiod are thought to be the two main factors directly involved in the timing of fish migrations to their spawning areas (Baril and Magnan, 2002; Blanchfield and Ridgway, 1997; Falke et al., 2010) and the final stages of gonad development (Pankhurst and Porter, 2003). The water temperature regime prior to the spawning season can also indirectly control fish reproduction through its effect on gonad development and maturation (Carscadden et al., 1997; Henderson, 1963). Hence, modelling the direct and indirect effects of environmental factors on the timing of fish reproduction represents a challenging task, especially for species spawning towards the end of the growing season. Brook trout (*Salvelinus fontinalis*), a freshwater fish species native to northeastern North America, was reported to spawn from late August to early December depending on latitude or elevation (Power, 1980). Because brook trout is a fall-spawning species found in a variety of freshwater habitats, it represents an excellent biological model for studying the phenology of fish reproduction.

In the Northern Hemisphere, the season cycle is characterized by the remarkable color change of deciduous trees, turning from green in summer to yellow or red colors in fall. Carotenoid and anthocyanin pigments are mainly responsible for leaf color change in fall and could help to protect leaf cells during senescence (Feild et al., 2001). Temperature and photoperiod are thought to be the main drivers of leaf color change in fall, but the timing of these fall phenological events has proved harder to predict than the timing of spring phenological events, probably because both direct and indirect effects of environmental factors are integrated over the growing season (Menzel et al., 2006; Vitasse et al., 2009). Monitoring vegetation phenology has become easier with the recent advent of digital imaging devices, allowing the development of “color indices” that can actively track the rhythm of seasons (Proulx and Parrott, 2008; Richardson et al., 2009).

The objective of this study was to evaluate the synchrony (i.e. the degree of overlap between two events; Miller-Rushing et al., 2010) between leaf color change in fall (hereafter leaf yellowing) and brook trout spawning at the scale of a wildlife reserve. Synchronized peaks of leaf yellowing and brook trout spawning would

* Corresponding author. Tel.: +1 819 376 5011x3368; fax: +1 819 376 5084.
E-mail address: marc.pepino@uqtr.ca (M. Pépino).

1470-160X/$ – see front matter
http://dx.doi.org/10.1016/j.ecolind.2013.01.036

suggest that freshwater and terrestrial processes are tightly (yet indirectly) coupled to environmental factors.

2. Materials and methods

2.1. Study area

The study was carried out in 2008, on a 135 km stretch across the Laurentides Wildlife Reserve (47°45′N, 71°15′W), Québec (Canada). The observation sites were located at elevations varying between 360 and 950 m (see the study area in the online version of the article). The area is characterized by a humid continental climate with harsh winters (mean annual temperature: 0.3 °C; annual snowfall: 639 cm). Watershed geology is largely homogeneous and consists of a metamorphic basement (gneiss) with intrusive rocks (mainly mangerites). Streambeds are shaped by glacial deposits and outwash. Vegetation cover is mainly composed of a continuous strip of mixed boreal forest dominated on mesic sites by balsam fir, *Abies balsamea*, and white birch, *Betula papyrifera*. Black spruce, *Picea mariana*, and jack pine, *Pinus banksiana*, are the other subdominant conifer species found in less favourable sites. A few other deciduous species, like trembling aspen, *Populus tremuloides*, and yellow birch, *Betula alleghaniensis*, are occasionally present. All deciduous species present in the region show a characteristic yellow coloration of their fall foliage. The vegetation of hydric sites is dominated by speckled alder, *Alnus rugosa*, tamarack larch, *Larix laricina*, and black spruce. Brook trout is the dominant fish species and lives in allopatry in most of the streams within the reserve (Pépino et al., 2012a).

To monitor temporal variations in brook trout spawning activity, we selected 12 stream reaches of approximately 1 km in length. These reaches were small tributaries (Strahler order 1–3), with a median slope of 2.5% (range 0.3–12.8%) and a gravel bed substrate, representing a set of conditions suitable for brook trout reproduction. Reproduction was observed to occur in all reaches surveyed (see details in Pépino et al., 2012b). Most of the spawners come from thermally stratified lakes connected to these reaches. An overview of many stream reaches is available in the online version of the article using the Street View option in Google Earth.

To monitor temporal variations in leaf yellowing, we selected eight photographic viewpoints regularly positioned along highway 73/175. We selected photographic viewpoints according to the following criteria: (i) site accessibility, (ii) proximity of stream reaches, and (iii) presence of deciduous tree species in the image scene. For half of the photographic viewpoints, the observer-to-vegetation distance was <100 m (close scenes), whereas it was >100 m (far scenes) in the other half. The conifer/deciduous vegetation cover ratio varied similarly within the categories of close and far scenes. One close scene was next to a stream reach (i.e., 165.93 km) while all other scenes were located on hillsides. The photographic viewpoints and scenes locations can be retrieved in the online version of the article.

2.2. Spawning season

We used redd counts to monitor the spawning activity of brook trout. A redd is a visible depression in the river substrate where the female buries its eggs (Power, 1980). We visited each stream reach weekly to count the number of redds (15 August to 19 October 2008). The visits began prior to the spawning season and continued until new redds could not be recorded (Table 1). During a visit, we observed spawning activity by walking slowly in an upstream direction along the stream bank. If a redd site was suspected, the observer would crouch down and wait for three minutes to detect the presence of spawners and spawning activity. The observer was equipped with polarized sunglasses, and visits were always conducted under high visibility conditions (i.e., bed substrate clearly visible with polarized sunglasses) to ensure consistency in the detection of redds. We confirmed the presence of redds by observing a clearly defined nest (disturbed streambed sediments with a characteristic pit tailspill formation), an actively digging female, or a male fighting for a stationary female (Blanchfield and Ridgway, 1997; Power, 1980). A single observer visited all reaches on a weekly basis between 15 August and 19 October. We recorded the longitudinal position of each redd (m) relative to flags spaced at 20 m intervals along the shore bank. This procedure allowed us to exclude previously observed redds and to count only recently observed ones. The spawning season of brook trout was summarized in a histogram showing the number of new redds recorded each week among the 12 stream reaches.

2.3. Image acquisition

We used digital images to monitor the temporal variations in leaf yellowing. Images were taken by the same observer using a digital compact camera (Canon PowerShot A550, Canon Canada Inc., Mississauga, ON, Canada) under natural light and using automatic settings (aperture and shutter speed). Other camera settings included the following: ISO 100, low-compression JPEG images of 2048 × 1536 pixels, focal length of 5.8 mm (35 mm equivalent), evaluative light metering, and daylight white balance mode. At each photographic viewpoint, two crosses identified the position of the observer's feet and the image scene was identified by the magnetic declination (compass angle) and the vertical inclination (handled clinometer; Suunto PM-5) of the camera. Natural landmarks (e.g., hilltops, tall trees, or rock piles) were used to align the images. During the redd count survey, we took between one

Table 1
Characteristics of the spawning season of 12 stream reaches in 2008. The peak of spawning represents the day when the number of redds was the highest. Stream reaches are identified by the milepost road distance from south (94.59 km) to north (209.08 km). *n*: total number of redds in each stream reach.

Reach	*n*	Elevation (m)	Peak of spawning	Spawning season	Survey period
94.59	143	685	26/09	26/09–14/10	11/09–19/10
96.37	49	669	10/10	19/09–10/10	08/09–19/10
101.63	5	801	03/10	21/09–03/10	06/09–10/10
104.10	29	805	25/09	18/09–15/10	06/09–15/10
104.67	95	818	25/09	08/09–19/10	01/09–19/10
113.32	9	789	13/09	13/09–28/09	06/09–03/09
133.11	31	825	24/09	16/09–08/10	05/09–15/10
143.75	36	790	10/09	03/09–01/10	03/09–15/10
161.70	89	769	23/09	11/09–07/10	04/09–15/10
165.93	35	761	23/09	03/09–09/10	15/08–16/10
174.33	22	760	05/10	23/09–14/10	05/09–14/10
209.08	8	372	18/09	14/09–30/09	07/09–05/09
Total	551	779	24/09	03/09–19/10	15/08–19/10