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## Using nature's clock to measure phenology

An important detail related to the timing of ecological events was omitted from Morisette *et al.*'s otherwise excellent review of the critical role of phenology in tracking 21st-century climate change (*Front Ecol Environ* 2009; **7[5]**: 253–60). Trends in the arrival of the vernal equinox (the "true" start of spring) create a bias in phenological records when these records are reported relative to calendar date, because the calendar date of the spring equinox occurs earlier each year throughout a given century (Sagarin 2001). The bias is created by the slight mismatch between the length of the true Earth year and the slightly longer average year on the Gregorian calendar, which we currently use to mark time. This bias will tend to cause researchers to overestimate trends toward earlier spring signals (budding, emergence from hibernation, migration, etc), but the exact magnitude of the bias cannot be predetermined. Moreover, the bias usually resets at the turn of each century (ie years divisible by 100) when a leap year is skipped, but the Gregorian calendar requires the year 2000 (and other centuries' opening years that are divisible by 400) to be a leap year, thereby allowing the bias to increase through the 21st century.

Fortunately, this bias can be easily corrected long after data collection, by recording phenological trends in relation to each year's true start of spring (vernal equinox) rather than by calendar day. Doing so preserves two key components of phenological data that were highlighted by Morisette *et al.* – the availability of long-term records and the accessibility of phenology to non-scientists. Phenology holds great promise to encourage people of all ages and abilities to venture into nature, wherever they live, and record what they see. Indeed, I discovered this bias while conducting my own analysis of an unusual phenologically related dataset – a now 92-year-old gambling contest to guess the exact minute of spring ice breakup in an Alaskan river (Sagarin and Micheli 2001).

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## Phenological trend estimation: a reply to Sagarin

Sagarin notes correctly the disparity between anthropocentric calendars and timekeeping that relies on orbital dynamics. We agree that the bias (up to 0.8 days per century; Sagarin 2001) induced by the difference between the solar calendar and the Gregorian calendar should be accounted for in any analyses of long-term trends where field observations are recorded by calendar day (rather than by solar position). An additional bias, not raised by Sagarin, is the change in the relative length of the seasons due to the precession of the equinoxes. This effect, while considerably less than a day per millennium (Meeus 1998), argues in favor of referencing phenological events in winter-dormant ecosystems to the winter solstice (rather than to the spring equinox, as suggested by Sagarin).

Although not accounting for these effects can bias estimates of phenological responses to climate change, we note that, in both cases, the effects are small relative to (1) the high interannual variability (a week or more from year to year) of the spring "green-wave" in temperate and boreal regions, which is driven principally by atmospheric circulation patterns and their anomalies and, secondarily, by local environmental constraints (Schwartz *et al.* 2006); and (2) the magnitude of the observed trends toward earlier spring (2.3–5.2 days per decade according to the IPCC AR4; Parry *et al.* 2007) over the past 30 years.

Independent of this point, our review (*Front Ecol Environ* 2009; **7[5]**: 253–60) highlights key advances and the growing importance of phenological research for addressing several pressing environmental challenges.

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