USA npn National Phenology Network

Taking the Pulse of Our Planet

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Phenology-Linked Indicators of Climate Change Impacts on Society and Ecosystems

"An indicator represents the state of certain environmental conditions over a given area and a specified period of time [1]."

In addition to increasing our understanding of current and future changes, the identification of indicators can greatly facilitate the communication of observed impacts of climate change to the public and decision-makers. Information derived from these indicators can then influence the design of an effective societal response to these impacts—most of which will affect the function of the ecosystem services that support human well-being around the globe [2].

Many species of migratory birds are shifting their arrival dates in spring and fall due to climate variability and change.

Phenology—the seasonal timing of life cycle events in plants and animals—is widely accepted as a robust, leading ecological indicator of the impacts of environmental variation and climate change on biodiversity and ecosystem processes across spatial and temporal scales [3, 4].

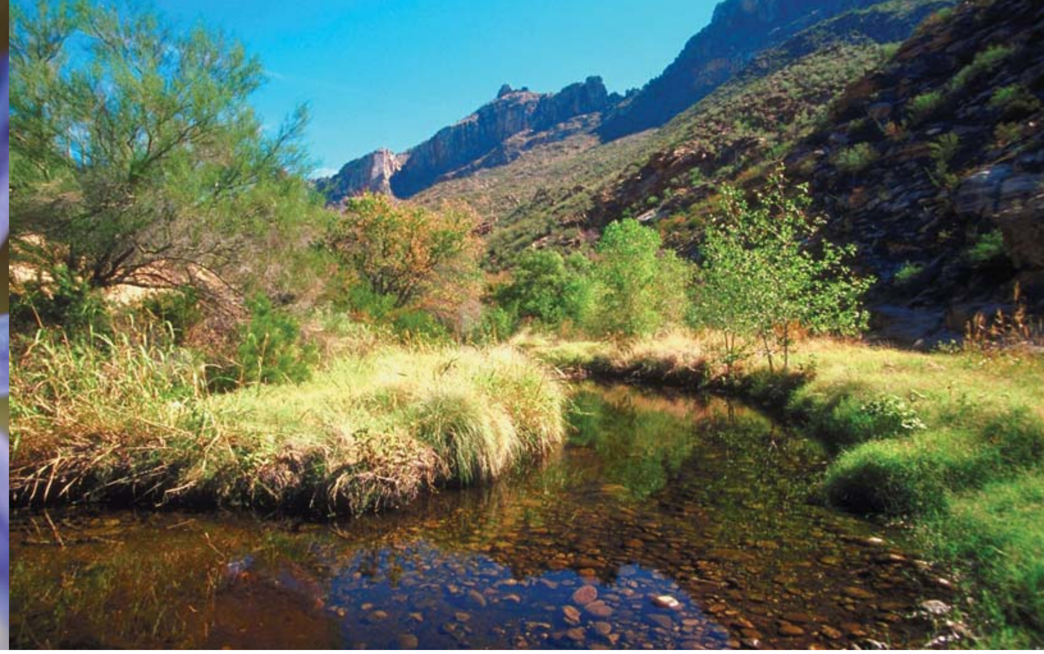
Many phenology-linked indicators have broad application across sectors and geographies. Depending on the application, phenology can be used as an indicator of species' sensitivity to climate change, an indicator of impacts on important ecological processes, or can be combined with climate data as an integrated indicator of climate change [5].

Selection of Additional Phenology Linked Indicators

"Leaf & Bloom Dates" (also known as the Spring Indices [6]) and "Length of the Growing Season" are well recognized already as key phenology-linked indicators of climate change impacts on society and ecosystems [1].

To identify additional phenology-linked indicators for use in national assessments of climate change, the USA National Phenology Network (USA-NPN) led an ad hoc working group through a selection process. The group, comprised of ten phenology experts, used the following criteria to rank their choices of up to five indicators:

- **Relevance:** The indicator is sufficiently sensitive in showing the effects of climate change such that it can be used in decision-making;
- **Scientific merit:** Established or developing theory and analysis methods from observation- and instrumentation-derived data sets that have shown climate-related multi-decadal trends across large geographic regions;
- **Data availability:**
  - Type 1: Adequate data are available and data generation is ongoing by systematic monitoring and collection efforts (likely source is indicated),
  - Type 2: Full or partial data generated by ongoing, systematic monitoring and/or collection are available, but either a complete cycle of data has not been collected, or further data analysis or management is needed to present a status or trend [7].



The Indicators

After a review of over fifteen proposed phenology-linked indicators, the USA-NPN compiled the indicator selections from each working group member. Six key indicators falling into three nested categories emerged from this process.

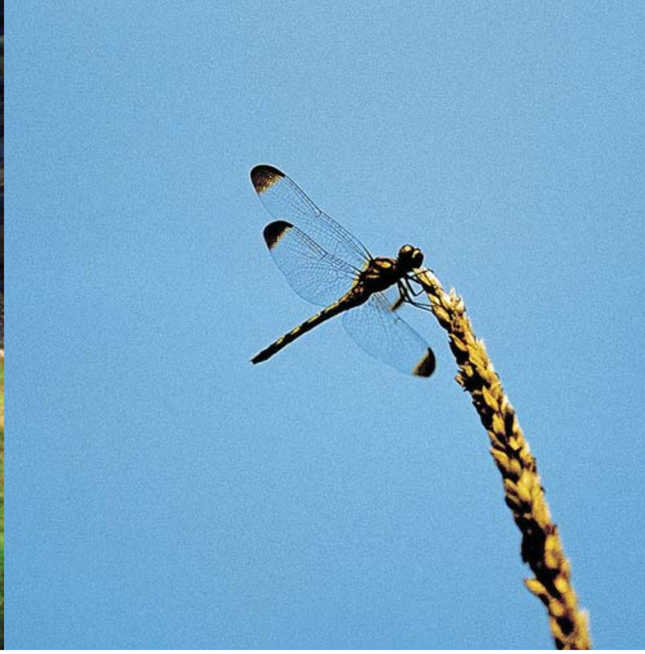
Climate-Derived Indicators

Indicator 1: Accumulated Growing Degree Days (GDD)
Description: Calculated as the number of days above a pre-specified temperature threshold; thresholds can be set relative to region and vegetation or crops.
Relevance: Indicator is critical to carbon, water, and nutrient cycles; this translates to plant primary production. GDD has been used to predict plant and insect development for planning management activities. Shifts to earlier and longer thermal accumulation can induce heat stress in many species, leading to changes in the timing of planting and irrigation. Earlier events may lead to ecological mis-matches between plants and pollinators; earlier release of pollen to air may affect people with allergies and asthma. In fisheries management, change in GDD may affect harvest dates or legal protection windows.
Scientific Merit/Data Availability: High/Type 1 (NOAA-NCDC)
Sectors: Agriculture, natural resource management, human health and welfare.

Indicator 2: Timing and Duration of Frost Days
Description: Several indices exist: (1) 'Frost period' is the number of days from first frost in fall to last date in spring, (2) 'Damage index' is the first leaf date minus last frost date, (3) 'Springtime frost surprise index' is the number of days in spring when minimum daily temperature (T) falls below freezing following the first 7-days when all Ts are warmer than a regionally-determined T threshold, (4) 'Fall frost surprise index' is the number of days when minimum T's drop below freezing prior to the onset of the first 7 days that are colder than a given T threshold.
Relevance: Frost periods are expected to decrease, yet 'frost surprises' are expected to occur with increased frequency. These events can lead to damage or mortality of plants, fruits and other crops, including those grown for biofuels. Cascading effects can occur, such as loss of food and habitat resources for many animals.
Scientific Merit/Data Availability: High/Type 1 (NOAA-NCDC)
Sectors: Agriculture, natural resource management, energy production.

Ecological Process Indicators

Indicator 3: Timing of Spring Stream Runoff from Snowmelt
Description: Technically referred to as center of mass, or centroid, of annual streamflow (CT); calculated as the trend in average CT from daily or monthly flow volumes stream gauges.
Relevance: Seasonal shifts in streamflow and overall alteration of the hydrological system (e.g., increased flashiness) in snowmelt-dominated systems have significant phenological implications for numerous organisms such as high elevation aquatic insects and fish life cycles (e.g., egg spawning and hatching), montane wildflower development, montane and lower altitude riparian forest function (e.g., timing of seed dispersal and recruitment in cottonwood forests, community displacement), and availability of water to downstream crops (e.g., too much from early flooding or too little in mid to late growing season). In particular, lack of water availability at times of peak thermal stress (i.e., during summer low flows) can lead to declines in biological fitness or mortality in plants and animals. Altered flood regimes can lead to erosion, scouring of streambeds, and increased sedimentation; this can lead to water quality issues downstream.



Scientific Merit/Data Availability: High/Type 2 (USGS)
Sectors: Agriculture, natural resource management, water

Indicator 4: Timing and Duration of Fire Season

Description: Different metrics can be used. For example, fire season start and duration can be based on reported first large fire (>100 acres) discovery, last discovery, and last control dates. Other fire-related metrics include the first calendar day exceeding the historical effective fuel density (EFD) value (i.e., the onset of fire season), the EFD frequency (the mean number of days per year exceeding the historical EFD value), and the Energy Release Component (ERC), a proxy for fuel moisture content and fire intensity that is the principle metric and decision tool for the National Fire Danger Rating System used to characterize the fire season.

Relevance: Earlier springs and dry summers tend to increase the risk of large fires due to fuel flammability, especially in forests with higher moisture availability and biomass when they are experiencing drier than normal summer conditions. Seasonal timing of fire can effect potential growth period and reproduction in fire-dependent species. Catastrophic wildfire can lead to wholesale changes in forest ecosystems, including their ability to cycle and sequester carbon. Forests can become net carbon sources rather than sinks. Water quality and in-stream habitat can also be affected by post-fire erosion and sedimentation.

Scientific Merit/Data Availability: High/Type 2 (NIFC, USDA)

Sectors: Forestry, natural resource management, agriculture, human health (smoke exposure), safety (hazards in wild-land-urban interface), air quality (emissions), and water management, especially in the western and southeastern U.S.

Organismal Indicators

Indicator 5: Timing of Insect Emergence

Description: Monitoring of insect abundance in relation to GDD is a common tool used in the agricultural pest management community. GDD also has been used to predict insect emergence with some success. The USDA Forest Service conducts aerial and ground detection surveys of forest pest populations on an annual basis to produce digital sketch maps. Tree-rings can be used to reconstruct insect outbreak host chronologies as a method of developing baseline patterns of insect population dynamics (defoliation significantly reduces radial growth and wood density during and after an outbreak year).

Relevance: Earlier and more frequent emergence of insect pests due to warmer, drier conditions can lead to outbreaks that can damage crops and forest systems. This can induce widespread mortality events in some host populations, especially in those suffering drought stress. Shifts in the timing of flowering in crops and natural plant populations with asynchronous shifts in insect emergence can lead to trophic mismatches that negatively affect pollination services and availability of food resources for animals. Emergence of insect disease vectors, such as mosquitos and ticks, can impact human health.

Scientific Merit/Data Availability: Medium High/Type 2 (USDA)

Sectors: Forestry, agriculture, human health.

Indicator 6: Migratory Bird Arrival and Departure Dates

Description: Long-term, standardized bird capture data are typically used to calculate a mean arrival date within the first quartile of records. Regional to continental ocean-climate patterns that influence the timing of migration can be tracked by the ENSO, PDO, and AMO indices and standard climate patterns.

Relevance: Many migratory bird species show varying long-term trends in their arrival dates to breeding (spring) and wintering (fall) grounds. As a result, migratory birds may be the most likely animals to experience trophic mismatches. This could affect ecosystem services such as eating insect

pests, seed dispersal, and pollination and could have implications for seasonal bird-watching activities. Changes in migratory patterns can also affect airport and roadway safety.

Scientific Merit/Data Availability: Medium High/Type 1-2 (AKN NOAA)

Sectors: Agriculture, natural resources, human health, tourism transportation.

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About the USA-NPN:

The USA National Phenology Network, established in 2007 as a partnership-driven program with leadership by USGS, is a national network that organizes and facilitates the collection and integration of phenological observations across space and time. Partners include citizen scientists resource managers, educators, and scientists from public agencies, Native American tribes, non-governmental organizations, specialized networks, and academic institutions. The primary goals of the USA-NPN are to understand how plants, animals and landscapes respond to environmental variation and climate change, and to develop tools and techniques to facilitate climate change adaptation by humans and natural systems. The Network will meet these goals through the development of information management systems, creation of partnerships, facilitation of research and development of decision-support tools, and promotion of education and outreach activities.

References:

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