

# Chapter 7 Time Series

The value of time series, both for climate-related variables (Hare and Mantua, 2000; McGowan, 1990) and for contaminants (AMAP, 1998), is undisputed. However, recognition of the potential of climate variables to produce variance in contaminant time series has all but been neglected (Macdonald *et al.*, 2002b). This report has discussed numerous examples of how global change can alter delivery of contaminants to and within the Arctic; alteration in wind fields and precipitation forced by the Arctic Oscillation (AO) being but one simple example. That the leading ‘global distillate’, water, provides one of the clearest detectors of global temperature change in its isotopic composition (Fischer *et al.*, 1998) should generate considerable anxiety about time series of volatile and semi-volatile compounds established from, e.g., atmospheric concentrations, ice cores, or sediment cores, even if the pathway between emission and point of measurement is reasonably direct. Examples closer to contaminant time series can be found. For instance, the mercury (Hg) record in ancient Antarctic ice has been suggested as a proxy for ocean productivity (Vandal *et al.*, 1993) and cadmium (Cd) has been applied in paleo ocean-productivity histories (Saager and deBaar, 1993; Shen *et al.*, 1987).

The environment can be monitored at many points (Figure 7-1), each of which will tell a separate story. For example, PCB concentrations might be measured as follows: in air at Alert every two weeks; in an ocean profile collected annually; in biota or surface sediments collected every five years; or in a dated sediment or ice core. What these PCB time-series data will indicate depends on how many environmental processes have an opportunity to operate on the original signal (the emission), and how the recorder (the medium being monitored) itself actually functions to modify the signal. Much research has been conducted to understand and account for the latter (e.g., studies of organochlorine compound (OC) cycles in female mammals; increase in Hg with age of fish, diagenesis in sediment cores; food-web studies, etc.) but the difficulties associated with climate variability creeping into the record have been mostly ignored. Climate variability by itself may cause aliasing. Aliasing, the result of sampling being conducted at a rate that does not resolve the natural frequencies (or period) of the system, can lead to situations where either the phenomenon is missed completely, or interpreted to have a lower frequency (or longer period). In the worst case, a cycle may be interpreted as a trend. For example, the

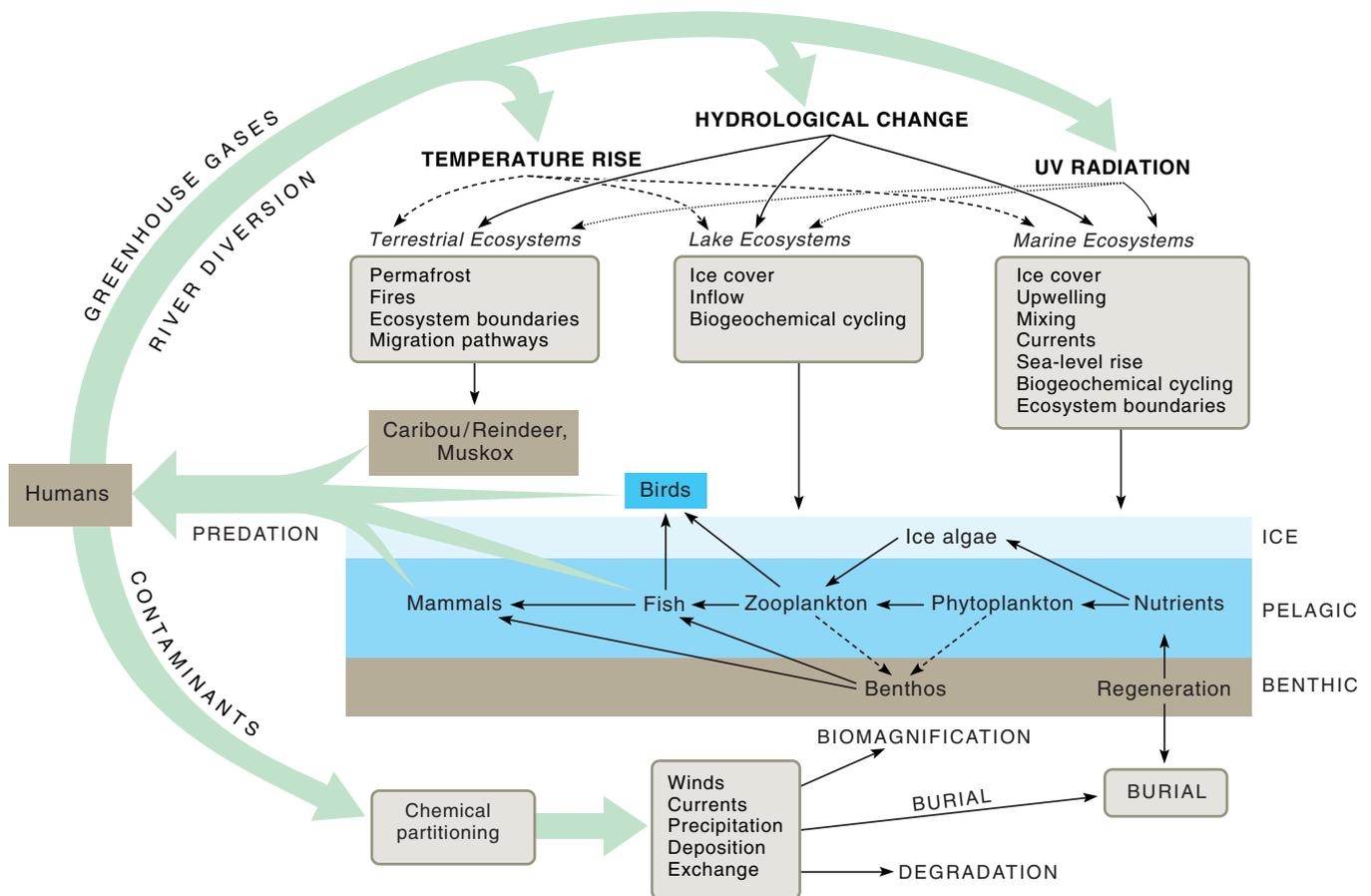


Figure 7-1. A schematic diagram of the pathways contaminants must traverse between emission and points at which environmental time series data are collected for the Arctic.

AO's time scale of five to seven years (Proshutinsky and Johnson, 1997) makes it very difficult to assess the role of such sub-decadal variation in data collected at five-year intervals. Furthermore, a trend from a time series collected from, for example, 1980 to 2000 will potentially carry a large bias, either positive or negative, produced by a switch in the middle of the record from generally AO<sup>-</sup> to strong AO<sup>+</sup> conditions. Climate change often may provide an alternate hypothesis for time-series contaminant data. A few examples are described briefly in sections 7.1 to 7.3.

### 7.1. Time series derived from sediment-core records and surface sediments

Well-dated cores from lakes and oceans provide an established means of estimating historical fluxes of contaminants (Lockhart *et al.*, 1995, 1998; Muir *et al.*, 1996). Provided the uneven spatial distribution of lake sedimentation rate (focusing) is taken into account, fluxes to sediments can be used to infer the flux to the surface of the water and thereby allow comparison with fluxes at other sites or with emissions. Increases or decreases in contaminant concentrations with depth in a sediment core are then often used to infer historical changes in emissions. However, between emission and burial at the bottom of the lake or ocean lie atmospheric transport, deposition to surface water or the drainage basin, attachment to particles, settling to accumulate at the bottom and, possibly, remobilization (Figure 7-1). Considering atmospherically transported contaminants, climate change may operate within this system to 1) change wind fields (important if there are atmospheric gradients); 2) change the efficiency of the air to ground transport (e.g., by altering precipitation or temperature); 3) change the efficiency of capture to sediments (by processes outlined in section 6.3.3.); 4) change the pathways of water currents; 5) change the supply of particles; and 6) change the carbon flux and metabolism in sediments thereby changing preservation.

Possibly the best example of how climate-related variables could interact with contaminant records in sediments has been revealed in lake sediments on Bjørnøya (Bear Island). The sediments of the lake Ellasjøen contain anomalously high OC concentrations that are attributed to large inputs of bird guano (AMAP, 2003b). What would a dated sediment core from such a lake show? It is clear that the record would contain a component deriving from the emission histories of various OC chemicals, but much of that signal would be mediated by birds. The population dynamics of birds, then, will alter the contaminant delivery over time depending on nesting locations and populations, and on the source and trophic level of their food which derives from the Barents and Nordic Seas (AMAP, 2003b), all of which are subject to climate variation. This example, which is particularly compelling in the way local and perhaps regional PCB patterns have been affected by biological sources (guano – see AMAP, 2003b; Enge *et al.*, 1998), is probably not an isolated example. There is also the importance of fish as agents for transporting OCs and Hg (Ewald *et al.*, 1998; Zhang *et al.*, 2001) which, together with high and variable anadromous fish escape-ments (Finney *et al.*, 2000, 2002), probably imprint an

as yet uninvestigated influence on the contaminant records in coastal lakes of Alaska.

Finally, natural variability in organic carbon flux to sediments can enhance sediment foraging (including small infauna and large animals such as diving birds, walrus, seals and belugas). A richer supply of metabolizable carbon feeds a more vigorous benthos (bivalves, worms, amphipods, etc.) and these, in turn, provide food to benthic feeders like birds, grey whales (*Eschrichtius robustus*) and walrus (*Odobenus rosmarus*). Variation in organic carbon flux, together with the potential for episodic colonization of sediments by new species under changing ocean climate (see for example Stull *et al.*, 1986), provides a strong caution on using surface sediment contaminant distributions to infer spatial or temporal trends in contaminants even where normalizing factors such as aluminum or organic carbon have been applied.

### 7.2. Time series in atmospheric concentrations

Data collections from air monitoring stations in the Arctic are of relatively short duration, extending back a couple of decades for metals (Sirois and Barrie, 1999), and less for OCs (see, for example, AMAP 2003a,b; Bailey *et al.*, 2000; Halsall *et al.*, 1998; Hung *et al.*, 2001; Macdonald *et al.*, 2000a; Stern *et al.*, 1997). There are fewer processes between the emission and the recorder for these measurements (Figure 7-1) but as discussed in previous sections, changes inherent in the AO (winds, ice cover, precipitation) are sufficient to imprint themselves on the emission before it reaches this recorder.

### 7.3. Time series in biological tissue residues

Marine and terrestrial biota have been collected to monitor bioaccumulating substances, especially the OCs and Hg (Addison and Smith, 1998; AMAP, 1998; Braune *et al.*, 1999; Wagemann *et al.*, 1995). Some programmes are based on an annual sampling strategy, however many utilize samples collected at very sparse intervals (typically 3-6 periods over a period of 20-30 years).  $\alpha$ -HCH concentrations in seals collected at Holman Island clearly do not follow atmospheric emissions (see Figure 7-2) nor do they follow Arctic air concentrations which mimic emissions quite closely (see Figure 9 in Macdonald *et al.*,

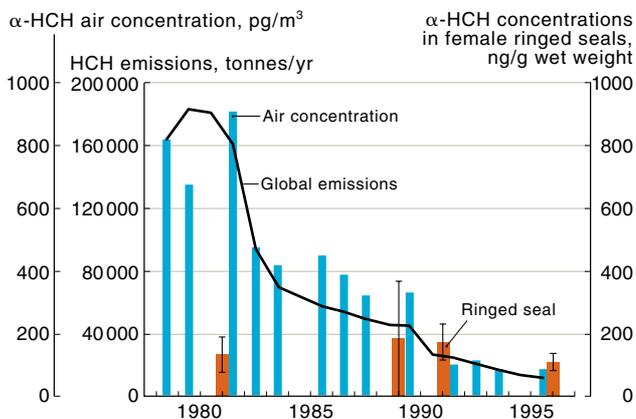


Figure 7-2. A comparison of time series concerning global emissions of  $\alpha$ -HCH, mean concentrations of  $\alpha$ -HCH in Arctic air and  $\alpha$ -HCH concentrations in Holman Island seals. The air concentration data were measured at different stations by several research groups (for data sources see Addison and Smith, 1998; Li *et al.*, 2002).

2000a). Instead, they approximately follow Canada Basin surface water concentrations, which makes sense given that seals obtain their HCH burden from a marine diet. The burden of  $\alpha$ -HCH is large in the surface waters of the Canada Basin (estimated at 1750 tonnes in the early 1990s, Macdonald *et al.*, 2000a), and not quickly changed. However, the burden can be altered by diversion of Russian rivers or by removal of ice cover, both of which occurred in the 1990s. Furthermore, change in the seal burdens can be caused by a regional change in the food web – something that has probably occurred as a consequence of changing ice cover and stratification

(Melnikov *et al.*, 2002). The food web factor might be ‘controlled for’ by monitoring trophic level through isotopic measurements ( $\delta^{15}\text{N}$ ) or by monitoring other components of the food web (e.g., Arctic cod (*Boreogadus saida*)) over the same time interval. The advantage of monitoring species at high trophic levels – that they are very sensitive to OCs and important to human diets – is somewhat offset by their sensitivity to variance from many factors other than emission strength (Figure 7-1). Given the five- to seven-year time scale inherent in change forced by the AO, time series data for biological tissue will be vulnerable to an unaccounted aliasing.