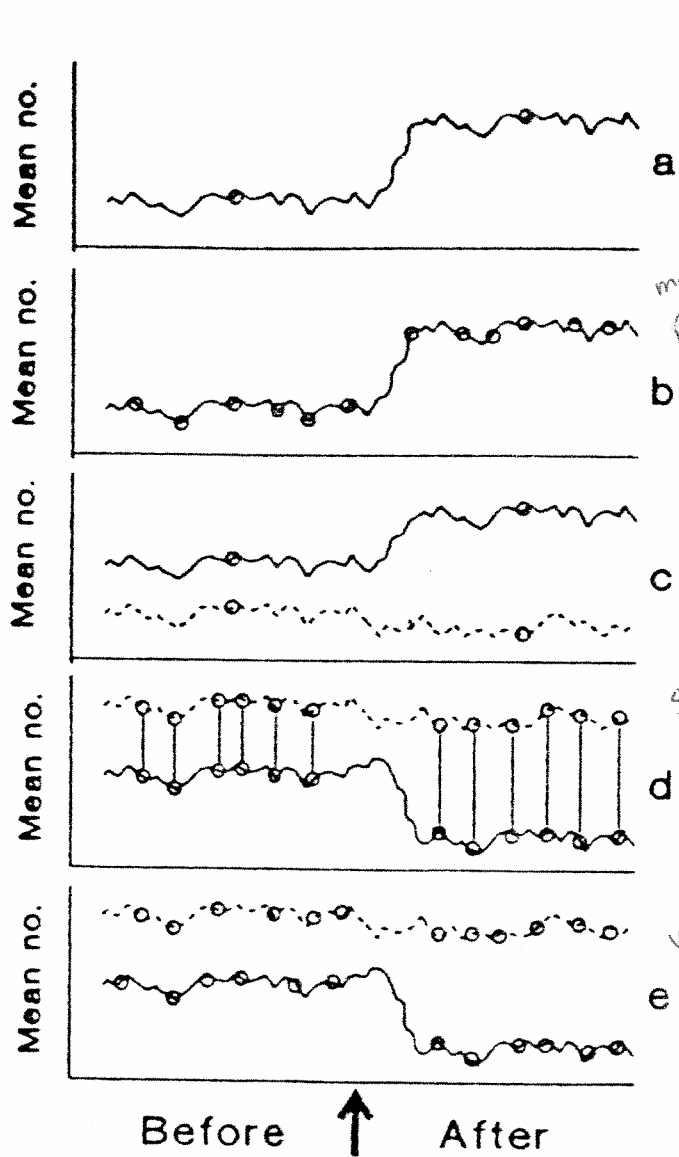


Detection of Environmental Impact



single
Bus A

multiple
B vs A

Green-
BACE

Stewart-
BACE

understanding
BACE

Fig. 1. Common sampling designs for environmental impacts, with circles indicating time of sample in one location before and time of the arrow; (b) random sampling before and after an impact; (c) BACE by Green (1979), with a single sampling point in each of a control (dashed line) and impacted location (solid line); (d) BACE by Bernstein and Zalinski (1983) and (1986); differences between mean at control and potentially impacted locations at times of sampling before and after impact (vertical lines indicate differences); (e) BACE (d) to allow sampling at different times (see text for further details).

These irrational forms of monitoring are sometimes even more irrational if no quantitative data were collected before an obvious incident. Information gathered afterwards in an attempt to demonstrate that environmental

TABLE 1. Analyses of variance in sampling designs to detect environmental impacts.

a) BACI design; data are collected in two locations (Impact and Control) at t randomly chosen times Before and After a planned disturbance. n replicate samples are taken at each time in each location. Relevant F ratios are calculated from expected values of Mean Squares as in Underwood (1981). B and C are fixed factors; Times are a random factor, nested in either Before or After.

Source of variation	Degrees of freedom	F ratio vs.	df for F ratio
Before vs. After = B	1	$T(B)$	
Control vs. Impact = C	1	$T(B)$	
$B \times C$	1	$T(B) \times C^*$	1, $2(t - 1)$
Times (Before or After) = $T(B)$	$2(t - 1)$	Residual	
$T(B) \times C$	$2(t - 1)$	Residual*	$2(t - 1), 4t(n - 1)$
Residual	$4t(n - 1)$		

b) Similar design, but there is a total of l locations sampled; locations are a random factor, otherwise details are as above. There is no formal test for comparing Before versus After. This is irrelevant because an impact must cause an interaction ($B \times L$ or $T(B) \times L$); see text for details.

Source of variation	Degrees of freedom	F ratio vs.	df for F ratio
Before vs. After = B	1	No test	
Among location = L	$l - 1$	$T(B) \times L$	
$B \times L$	$l - 1$	$T(B) \times L$	$(l - 1), 2(t - 1)(l - 1)$
Times (Before or After) = $T(B)$	$2(t - 1)$	$T(B) \times L$	
$T(B) \times L$	$2(t - 1)(l - 1)$	Residual	
Residual	$2lt(n - 1)$		$2(t - 1)(l - 1), 2lt(n - 1)$

* This test is identical to the t test recommended by Stewart-Oaten et al. (1986).

instead, alter the temporal pattern of variance of abundance (Fig. 1C). Analysis of appropriate sampling for these is not considered in detail in this review, having been described in full in a previous paper (Underwood 1991).

The final part of this discussion is a consideration of the ecological research programs necessary to replace specific regimes of sampling to detect particular environmental impacts. These are required to solve the usual problem of a lack of sufficient time to sample before a possible impact and the lack of statistical power in many sampling designs used to detect impacts.

ASYMMETRICAL SAMPLING DESIGN TO DETECT ENVIRONMENTAL IMPACT

First, consider the BACI design advocated by Bernstein and Zalinski (1983) and Stewart-Oaten et al. (1986). The analysis of variance of this design is summarized in Table 1a. As described in Underwood (1991), the F ratio indicated in Table 1a is the t test recommended by these authors. Also in Table 1b is the same analysis, extended to compare abundances in more than two locations.

In Table 2, the asymmetrical analysis is described, using a modelled set of data illustrated in Fig. 2A. Now, the useful contrasts of the Impacted vs. Control locations and its interactions with time can be extracted from the variation among all locations and its interaction with time.

An environmental impact should now be evident, in the simplest case, as an interaction between the difference between the mean abundance in the Impacted

location and that in the Control locations Before compared to After the disturbance began (i.e., Table 2: $B \times T$; see Fig. 3 and Table 3 for examples). Alternatively, if the impact is not sustained, nor sufficient to alter the mean abundance in the impacted location over all times of sampling after the disturbance, it should be detected in the pattern of statistical interaction between the times of sampling and the contrast of the Impacted and Control locations (i.e., Table 2: $T(\text{Aft}) \times T$). This is explained in full in Underwood (1992) and illustrated below.

Thus, a difference is sought between the time-course in the putatively impacted location and that in the controls. Such a difference would indicate an unusual event affecting mean abundance of the population in the single disturbed location, at the time the disturbance began, compared with what occurred elsewhere in undisturbed controls. The impact will either be detected as a different pattern of interaction among the times of sampling or at the larger time scale of Before to After the disturbance.

The patterns of significance in such analyses, under different types of responses to disturbance are illustrated below.

PATTERNS IN ANALYSES TO DETECT ENVIRONMENTAL IMPACTS

It is informative to consider disturbances of two types—pulse and press (Bender et al. 1984). The former are not sustained; the disturbance is removed after a period, although effects may be longer term. The latter are sustained disturbances. In environmental distur-

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...types of this design are several. First, routine, fixed-interval monitoring, in terms of pers because it could often be done by modifying the to programme of monitoring. Often, monitoring is monthly, basis (or at some smaller time-scale) for routine, fashion, or lack of imagination. Under suc of samples could still be taken but would be arrange patterns of difference in mean abundances of the r

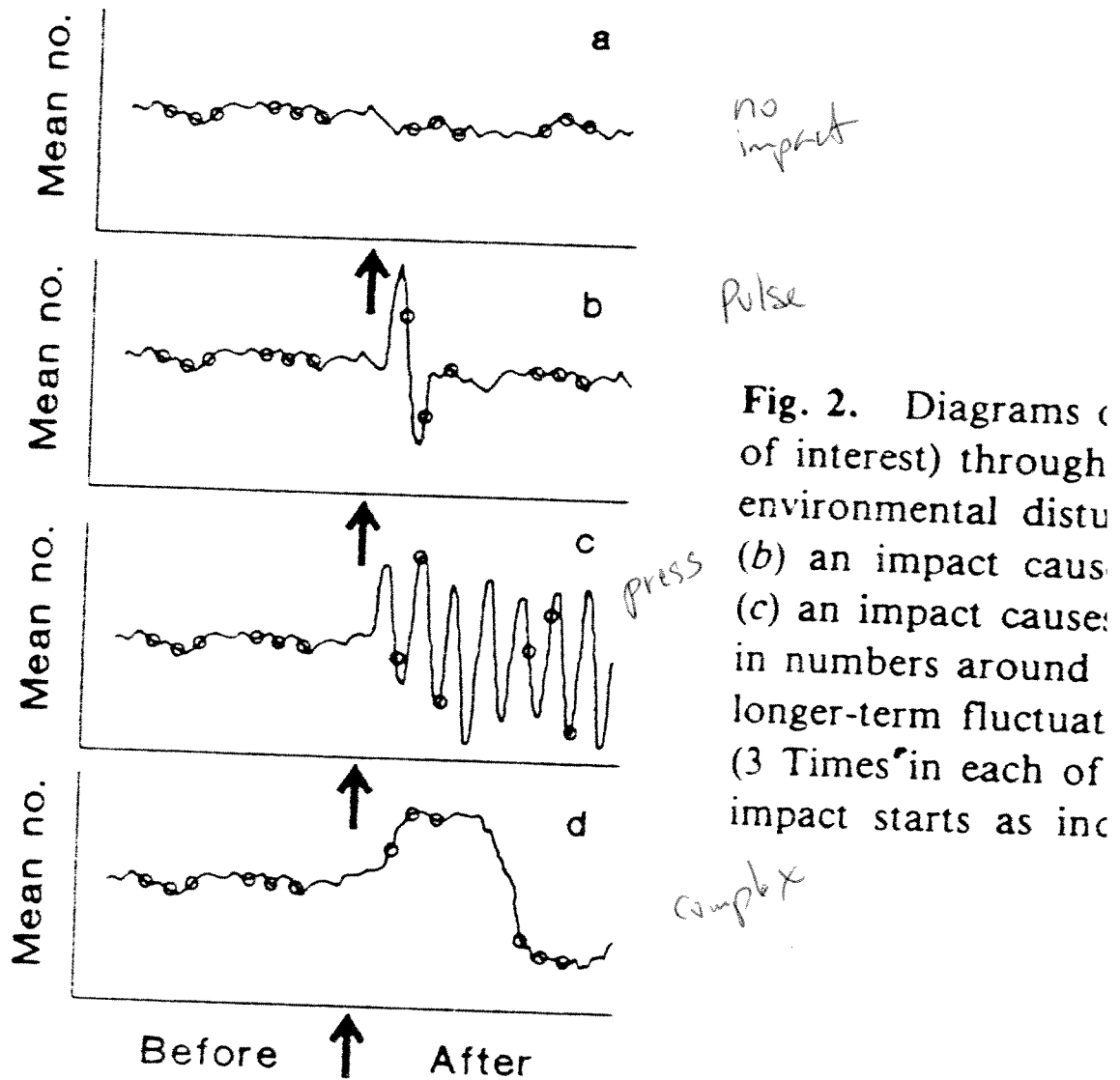


Fig. 2. Diagrams (of interest) through environmental disturbance (b) an impact causes a pulse in numbers around longer-term fluctuations (3 Times in each of impact starts as inc

Table 2. Sample data for an imaginary population subject to four conditions (as illustrated in Fig. 2): *a* is no disturbance causing increased rapid fluctuations, *d* is a press (as in Figs 2a-2d). In each case, the location was sampled at regular intervals in each of two periods (for example, 6 months apart) before

Source of variation

Before versus After = B

Among Locations = L

^aImpact versus Controls = I

^aAmong Controls = C

Times (B) = T(B)

B × L

^aB × I

^aB × C

T (B) × L .

^aTimes (Before) × L

^aT(Bef) × I

^aT(Bef) × C

^aTimes (After) × L

^aT(After) × I

^aT(After) × C

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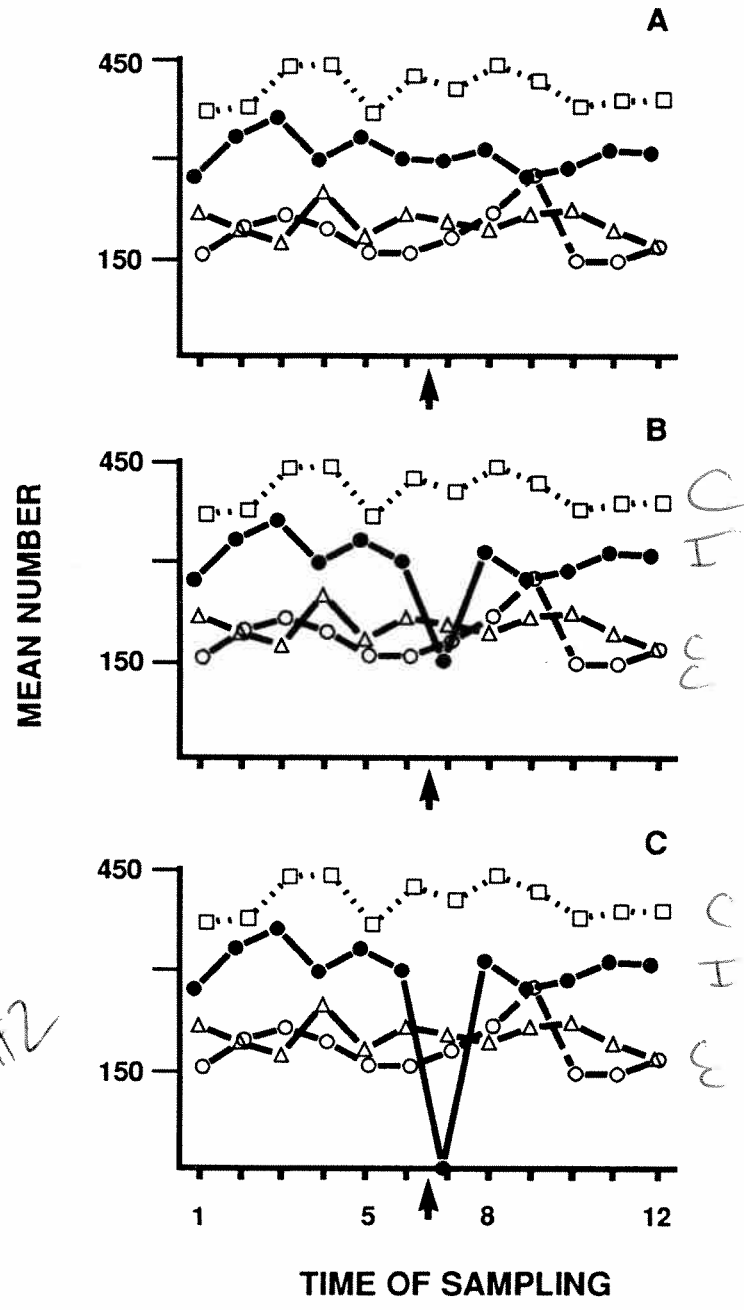


Figure 9.2. Simulated environmental disturbances in one location (solid line), with three Controls, all sampled six times Before and After the disturbance (at the time indicated by the arrow). These data are analyzed in Table 9.3. (A) No effect of the disturbance; (B) a pulse reduction to 0.5 of the original mean; (C) a pulse reduction to 0.

The analysis of such data is modeled in Table 9.3, assuming that residual variances (i.e., among samples at each time and location) were not altered by the disturbance. To simulate the impact, the mean number of animals at the seventh time of sampling (the first after the impact) was reduced by the requisite proportion.

The effect on the analysis of the data is obvious in Table 9.3. There is now a significant interaction between the difference between Impact and Control

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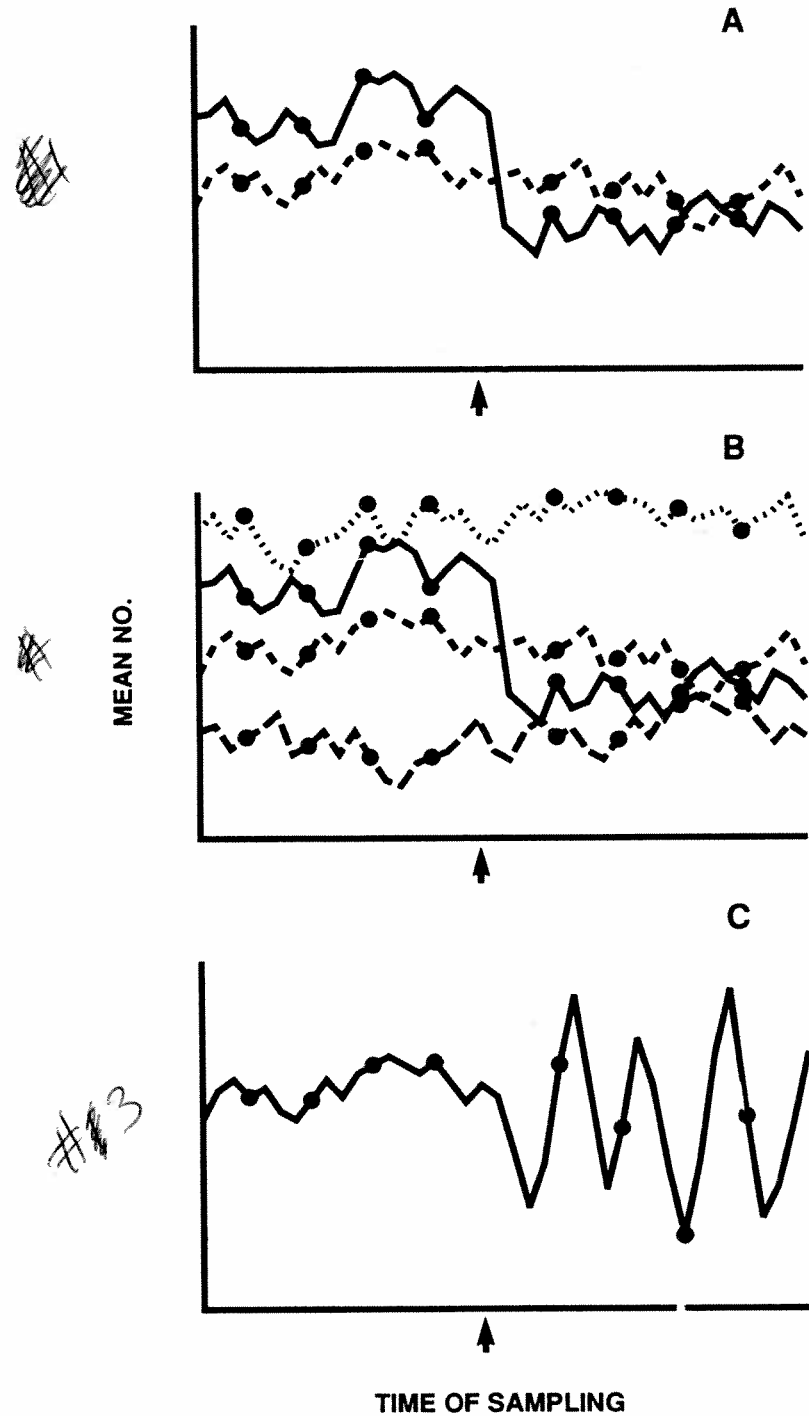
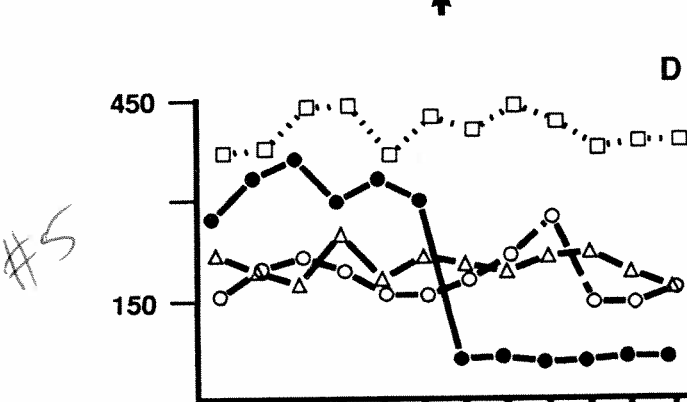
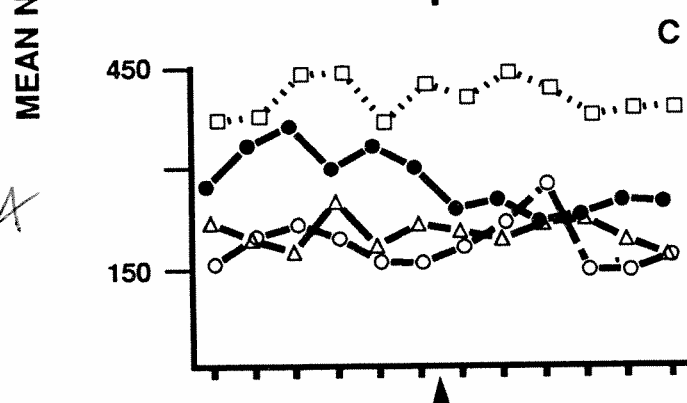
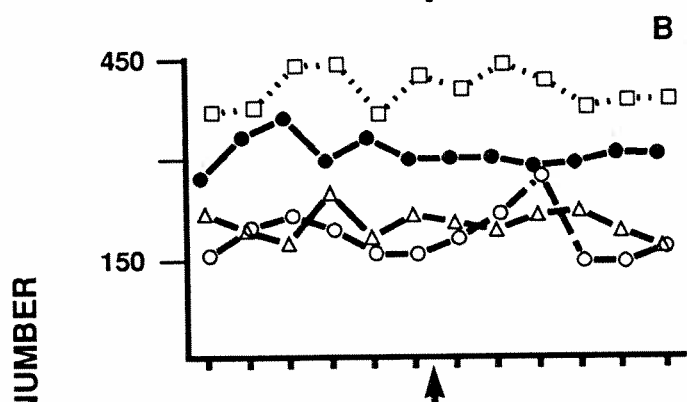
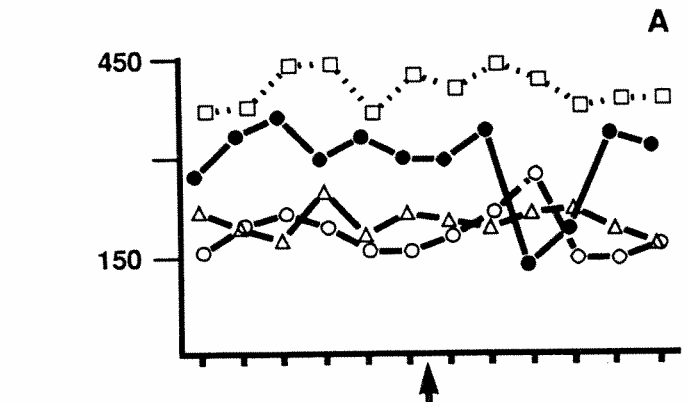


Figure 9.1. Sampling to detect environmental impacts. (A) BACIPS design; replicated samples are taken at several times in a single control (dashed line) and the potentially impacted location (solid line) Before and After a planned disturbance (at the time indicated by the arrow). (B) Sampling three Control locations to provide spatial replication. (C) An impact that has no effect on long-run mean abundance, but causes greater temporal variation.



#4

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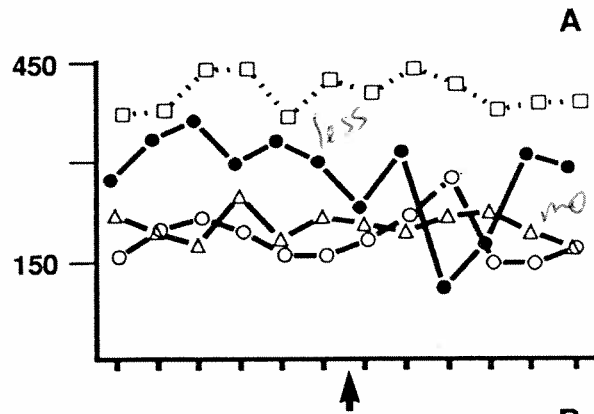
#5

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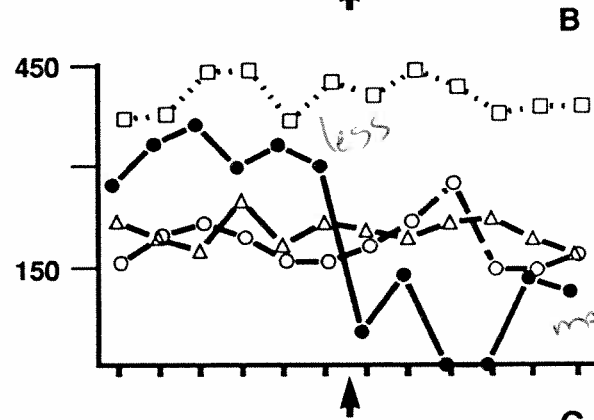
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TIME OF SAMPLING

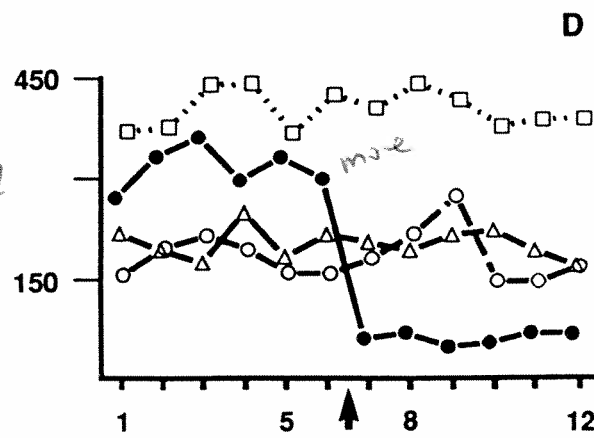
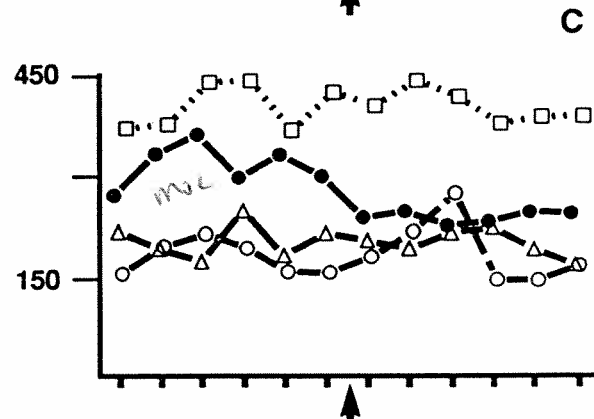
MEAN NUMBER



Δ in mean & SD



Variability & Press



Combinations of effects

Press & temporal Variability

#7

TIME OF SAMPLING

