Supplementary Materials

S. Calculating Evolutionary Rates

S.1. Arithmetic Rates of Diversification

In analogy to birth–death rates in populations, diversification rate or clade growth is a function of speciation and extinction. It can be calculated using arithmetic or exponential growth functions. *Arithmetic rates* are calculated based on the number of new taxa arising or going extinct per time interval, in relation to the total species richness within that time interval. Thus, an average fractional rate of increase (or decrease):

$$\text{Speciation rate: } R_S = (1/D)(FO/t) \qquad \text{(S1)}$$

$$\text{Extinction rate: } R_E = (1/D)(LO/t) \qquad \text{(S2)}$$

where D is total species richness, FO the number of first occurrences, LO the number of last occurrences and t is the time interval in Myr. Often equal time bins are employed in time series comparisons, so that the "rate" becomes a proportional change across equal time-steps. If multiplied by 100, it constitutes a percentage change [*cf.* Bown et al, 2004].

Following this, diversification and evolutionary turnover rates are defined as:

$$\text{Diversification rate: } R_D = R_S - R_E \qquad \text{(S3)}$$

$$\text{Turnover rate: } R_T = R_S + R_E \qquad \text{(S4)}$$

S.2. Exponential Rates of Diversification

Stanley [1979] advocated *exponential rates* in considering clade growth (or adaptive radiation). He only compiled values of R for modern clades in "the midst of unbridled radiation", based on the number of extant taxa and the age of the clade (time of origin until Recent), based on the exponential equation for population growth:

$$dN/dt = RN \qquad \text{(S5)}$$

where N is number of species, t is time and R is fractional increase per unit time.
Integrating,

$$N = N_0 e^{Rt} \qquad \text{(S6)}$$

Then, exponential (clade) growth, R (Myr^{-1}) is defined as:

$$R = \ln(D_1/D_0)/(t_0\text{-}t_1) \qquad \text{(S7)}$$

Where D_0 is species richness at t_0, the time of origin or FO of the clade and D_1 is the extant species richness, t_1=0 Myr.
A doubling time, in Myr, is calculated by:

$$T_2 = \ln(2)/R \qquad \text{(S8)}$$

As already noted by Stanley [1979, p. 104], "no radiation will follow exponential increase precisely or even approximate it for a long period of time". However, if restricting analysis to taxa in early stages of adaptive radiation, the increase will be approximately exponential.

S.3. Fossil Time Series of Diversification

Given the fact that we have access to fossil time series of coccolithophore morphospecies diversity (not only the modern species richness and the origination time of the clade; *cf.* Stanley [1979]), we adopted an approach investigating the change in exponential clade growth rates over time for major coccolithophore families with high and consistent preservation potential and an abundant fossil record. By converting D_t (species richness at time t) to $\ln(D_t)$ and performing linear regression of $\ln(D_t)$ on t over the intervals that have a log-linear character, we can derive a first-order estimate of diversification rate (Figure 5).

S.4. Exponential Rates of Extinction

Background extinction rates can be estimated from the average longevity of morphospecies within a clade (arithmetically, the inverse of longevity). Even if lineages vary in longevity, each one can be viewed as having contributed to its own extinction rate to the total [Stanley 1979]. Van Valen [1973] posited that within an ecologically homogeneous taxonomic group (herein a family), extinction occurs at a random, but constant rate, which is very similar to the decay of a radioactive element (see also Raup, [1975]). That means that the probability of extinction is equal for all taxa (genus, species) within a higher taxon (family) and does not increase or decrease systematically during the timespan of a taxon. In other words, a long-lived taxon has the same probability to go extinct as a short-lived taxon if they occupy the same adaptive zone or niche, and share highly similar traits. We apply this as a first-order comparative measure between coccolithophore families.

Linear survivorship equation:

$$S_t = S_0 e^{-\lambda t} \quad \text{(S9)}$$

S_0 and S_t are the number of survivors at the beginning and after t time units. Lambda (λ) is the rate of extinction per unit of time and is proportional to the slope of the survivorship curve (Figure 6).

References

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