Clocks which run according to the moon
Influence of the moon on the earth and its life

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Spagetti-eater? See chapter 4.2[1]

[1]Drawn by Mareike Förster after a figure in Geo, December 1984

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I will lift up mine eyes unto the mountains: from whence shall my help come?

My help cometh from the LORD, who made heaven and earth.

He will not suffer thy foot to be moved; He that keepeth thee will not slumber.

Behold, He that keepeth Israel doth neither slumber nor sleep.

The LORD is thy keeper; the LORD is thy shade upon thy right hand.

The sun shall not smite thee by day, nor the moon by night.

The LORD shall keep thee from all evil; He shall keep thy soul.

The LORD shall guard thy going out and thy coming in, from this time forth and for ever.

Psalms Chapter 121

Introduction and overview

Since anxient times the periodic change between full moon and new moon in a rhythm of 29 days has stimulated the phantasy of humans. In spite of it, not many people know the physical basics causing this change and the consequences of the orbiting moon on the earth and its creatures.

The moon orbits the earth as its satellite. Whereas the earth turns around its axis ones a day and orbits the sun during the course of a year, the moons orbit lags that of the earth. Instead of 24 hours it needs 24.8 hours. This is the cause of the forces which lead on the earth and especially in the seas to tides: The sea level lifts and sinks and low tides and high tides arise. This affects the organisms at the sea coasts. We will get to know some of these animals. A book of Palmer (1995b) and of Endres and Schad (1997) offer a good overview on organisms possessing tidal rhythms, rhythms with fourteen day periods and monthly rhythms.

First of all we have to understand, how the tides arise (chapter 1). Afterward we will look at some examples for tidal rhythms (chapter 2). The tides are amplified or weakened by the moon's position relative to the sun and the earth which results in a forteen-day rhythm. Spring- and neap tides arise. Many organisms have also adapted to this rhythm (chapter 3). The monthly repetition of the same moon-earth-constellation is used by numerous organisms to drive a lunar rhythm (chapter 4). Finally we will try to find out whether influences of the moon are also detectable in humans (section 4.3 in chapter 4).

1 How the tides arise

Due to the slower orbiting of the moon around the earth the tides of the oceans arise. This leads to low and high tides. The position of the sun and the moon in respect to the earth amplifies or weakens the tides. The pattern of the tides is furthermore modified by other factors.

While orbiting once in a year the sun, the earth spins during 24 hours around its own axis. Its satellite, the moon, takes, however, 24.8 hours for a turn. Therefore the constellation earth-moon-sun changes continuously, but in a regular order. Therefore the moon appears as half moon, full moon or new moon.

According to Newtons law of gravity two celestial bodies such as earth and moon attract each other. The attracting force decreases with the square of the distance between the two bodies. Written as an equation k $= m_1 * m_2/d^2$, where k is the gravitational attraction, m_1 the mass of body 1, m_2 the mass of body 2, d the distance between the two bodies. This is shown in figure 1.1 for the point A on the earth surface facing the moon, the center of the earth M, and the point B on the earth surface opposite to the moon by the different sizes of the arrows.

Each day there two tides of the oceans are observed. How do they arise? The gravitational force of the moon could be responsible for attracting the water masses of the part of the earth facing the moon. Earth and moon turn around their common center of mass (red point S in figure 1.1)

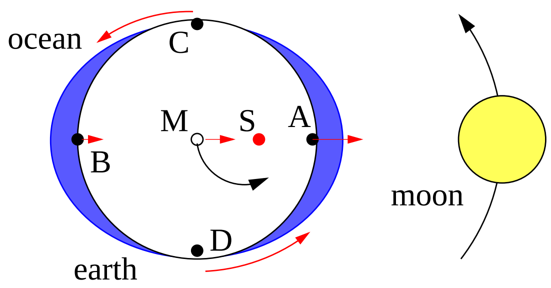

Figure 1.1: *Gravitational acceleration (red arrows) of the moon (yellow) on different locations on the earth. In A it is stronger as compared to M, the center of the earth, and there it is stronger as compared to point B at the opposite side. The center of the globe M turns around S (red point), which is the center of mass of the system earth-moon. The waters of the oceans (blue) are drawn away from C and D by the differences in gravitational acceleration of the moon. The result are* two *tides per day (12.4 hours apart). Note that the waters are not lifted up (the gravitational forces are much too small), but tangentially withdrawn from C and D toward B and A (long red arrows). After Keller (2001).*

once in a sideric month[1] (27 days 7 hours 43 minutes). This center of mass is not the center of the earth. It is about 2/3 of the earth radius away from it. Therefore centrifugal forces develop during the spinning. They could be responsible for the second tide on the opposite side of the earth.

However, this explanation is wrong. First of all, the gravitational acceleration, which binds the water to our planet, is 300 000 times stronger as the one of the moon. The moon is therefore not able to lift the water masses of the oceans up. Secondly, the tides at the opposite side to the moon are almost as high (just 4% less) as the tides on the surface of the earth facing the moon. Thirdly, the centrifugal forces of the earth-moon system are very low and can not explain the bulging of the water masses on earth at the opposite side of the moon.

The correct explanation of the cause of the tides is the following: In point A (figure 1.1) the water bulges, because the earth rotates faster than the moon. The water masses are therefore *tangentially* torn away from the solid earth. In point B the water stays back due to its mass inertia, while the solid globe is torn away from the water. In this way the waters are moved away from the points C and D toward A and B. Thus the moon does not lift up the water, but moves it tangentially along the earth´s surface. Imagine you have made a large snow ball. You are not able to lift it, although you produced it without much effort by rolling it.

In addition, the tides are also influenced by the sun. It is 400 times further away as the moon, but has a 1800 times larger gravitational acceleration. However, since the gravitational acceleration is proportional to the reciprocal of the 3rd power of the distance l ($b = 2Gr*m/l^3$, where b is the gravitational acceleration, G the gravity constant, r the earth radius, and l the distance earth-sun), the gravitational acceleration amounts to 45% of that of the moon only. During syzygia (full moon, new moon) the forces of the moon and sun add up and lead to spring tides, whereas during half moon the forces of the sun reduce those of the moon and neap tides result (figure 1.2).

The tides on earth are additionally influenced, because the moon does not circle around the earth, but has an elliptic orbit. During *perigeum* the moon is 9 to 14 % closer to the earth as compared to an *apogeum*. The tidal effects are therefore 30 to 48 % stronger. In combination with syzygia extreme tides (‘*perigean spring tides´*) arise.

Other factors influence the tides. The highest flood bulge is located at the *sublunar point* (the place on the earth surface where the moon passes the zenit); this place depends on the moon *declination*.

Quite a number of rhythms affect the tides: Half of the lunar day (12 hours 25 minutes), half of the sun day (12 hours), half of the synodic[2] month (14.77d), half of the sideric month (13.66d), the anomalistic month (27.55d), half annual variation of the sun declination (182.6 d), the anomalistic year (365.26d), the prograde year (8.8years), retrograde turn of the nodeline (18.6y).

Tidal effects are mainly found at the coasts of the oceans. *Geophysical factors* such as resonance properties of the ocean, current straits, course of the coasts, local features such as funnel shaped river mouths influence the tidal pattern and the height of tides. Due to these factors and their various combinations the tidal lift, which is 35 cm only at the open sea, can accumulate at the coasts and reach heights up to 4 m (German North Sea), 7 m (French Atlantic coast, see figure 1.3) and 21 m (certain fun-

[1] orbit in respect to the position of the stars

[2] in respect to the earth-moon constellation

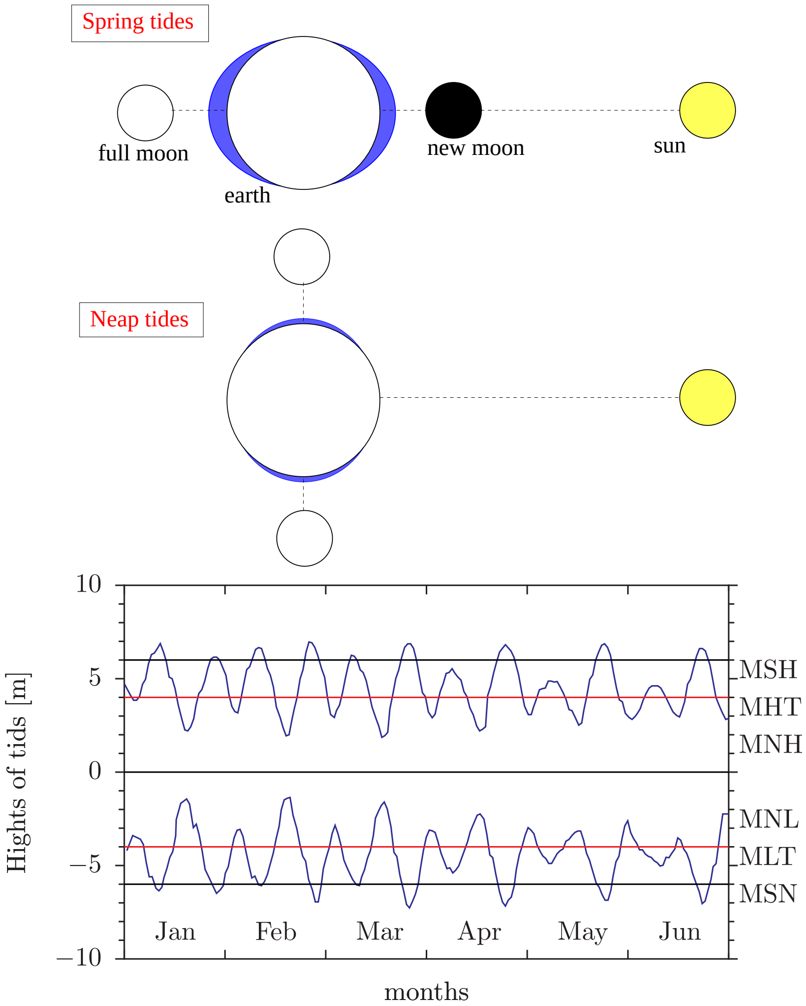

Figure 1.2: *Monthly occurrence of spring-and neaptides. If moon and sun are lined up with the earth (new moon or full moon, upper part), the tides are enforced (*springtide*). If moon and sun are perpendicular to the earth (first and last quarter of the moon), the heights of the tides are reduced (*neaptides*). As a result the tides are modulated in amplitude during the course of a month (bottom, MHT: mean high-tide, MLT: mean low-tide, MSH: mean spring high-tide, MSN: mean spring neaptide, MNH: mean neap high-tides, MNN: mean neap low-tides, in meters, ordinate). After Palmer (1974).*

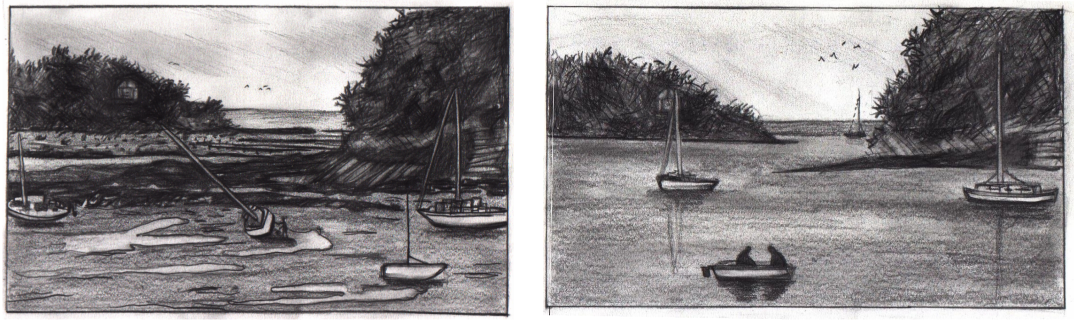

Figure 1.3: *Low tide (left) and high tide (right) in the harbour of St. Briac at the french Atlantic coast. The differences of the tides amount up to ten meters. Drawn by Mareike Förster after a figure in Geo December 1984.*

nel shaped river mouths).

The kind of tidal movements can be quite different: Usually there are tides with two low tides and two high tides per day. There are, however, also tides with only one change of high and low tide per day or mixed forms (see Barnwell (1976) for an overview).

In the eulitoral of the coast (zone between the highest high tide and the lowest low tide) the conditions change drastically (figure 1.4). Depending on whether this zone is exposed to the surf or protected from it, whether the coast is flat or steep, temperature, humidity, flooding, oxygen content and food supply, salt content, pressure, undulation and light conditions change (see for an overview Newell (1979)). The differences in the tides can be just a few centimeters or amount to more than ten meters. If the coast is very flat, the tidal zone might cover several kilometers.

The organisms of the coasts and oceans have to adapt to these tides. They show indeed tidal rhythms, fourteen day and 28 day rhythms. In the following we will get to know some examples for tidal rhythms, fourteen day and monthly rhythms (literature: Neumann (1981), Palmer (1974), Brady (1982), Palmer (1995b)).

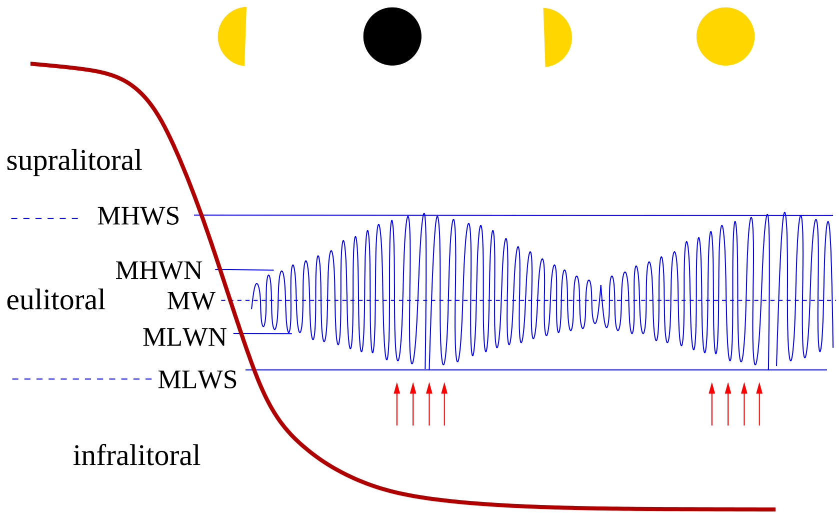

Figure 1.4: *Supra-, eu- and infralitoral at the sea coast with mean high tide of the spring- (MHWS, blue line) and of the neap tides (MHWN) and mean low tide of the neap- (MNWN) and spring tides (MNWS). Mean water level MW: stippled blue line. Neap tides after half moon (top), spring tides after full- and new moon. The red arrows at low tide during the spring tide period of the water movements refer to the eclosion days of the* Clunio *midge (section 3.3). After Caspers (1951) and Neumann (1966).*

2 Tidal rhythms

Many organisms at the sea coasts have adapted to the tides. We will have a closer look at these tidal clocks in an alga which lives at the beach, and a small crustacean, again a beach inhabitant.

Tidal rhythms are found mainly in animals of the sea coasts. They have been described in crabs (fiddler crabs), crayfish (*Carcinus*, *Emerita*, locomotor activity and color change of the carapax), mites at the sea shore, and in shells (limpet *Patella*). In insects tidal rhythms have been described relatively rarely. A terrestrial beetle at the beach, *Thalasotrechus barbarae*, is an example. A cave cricket (*Ceuthophilaus maculatos*) was claimed to possess a tidal rhythm. Coastal fish such as *Blennius* show tidal rhythms (Gibson (1965), Gibson (1967), Gibson (1971)). Among birds the reef-heron has a tidal rhythm: It flies at low tides to the sea, although it rests on trees far away from the coast. Even in unicellular algae tidal rhythms are known: The commuter diatom *Hantzschia virgata* (Palmer (1976)) is an example. More on this alga in the next section.

2.1 The up and down of the commuter diatome

At the sea shore occassionaly large amounts of unicellular algae are found. They cover the range on which the tides impinge and the sand or decayed material can show the green or golden colour of their pigments. During the high tide and during the night the algae are buried in the beach, during low tide they move to the surface in order to produce sugar in the sunlight. Sometimes they can even be heard, because oxygen is produced during photosynthesis which rises in gas bubbles. If they burst, a gentle noise is produced.

One of these algae is *Hantzschia virgata*. It belongs to the diatomes, the largest group among the algae (figure 2.1).

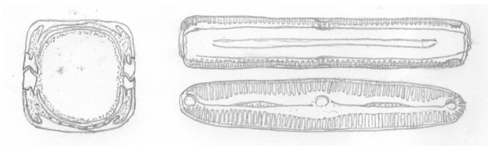

Figure 2.1: *Example of a diatome (here:* Pinnularia viridis*). Two shells made of silicic acid are interlaced like a shoe box (top right and cross section left). At bottom right a long groove (raphe) is visible, out of which cytoplasm is ejected at the front and moves backward. This moves the cell forward. Drawn by the author according to a figure by Pfitzer (right) and Lauterborn (left), from Biologische Einführungsübungen; Kurstage; Fakultätszentrum für Botanik der Universität Hannover, Sommersemester 2007*

Hantzschia can be found in large numbers at the beach not far away from the marine biological institute at Woods Hole in Massachusetts in the United States. During the night and at low tide none of them can be seen, during low tide at the day they cover as a golden lawn the beach. They are able to move by using the repulsion principle. At the small posterior part of the silicic acid wall they eject a mucus out of pores which moves the alga upward or downward. They cover only small distances, about 0.2 mm, but that is enough to submerge in the sand (figure 2.2).

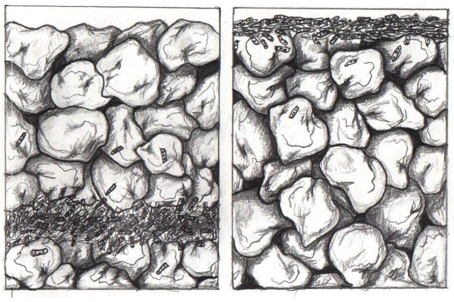

Figure 2.2: *Vertical migration of the diatom* Hantzschia virgata *in beach sand. Left during the high tide and in the night, about 0.2 mm deep in the fine sand, right during low tide at the day at the surface of the beach. The diatoms are able to move by ejecting a mucus out of pores at the thinner end of the glass-like cell walls. This periodic migration to the surface and into the sand continues under constant conditions in the laboratory for at least eleven days. Drawn by Mareike Förster after a figure in Palmer (1995b).*

This tidal rhythm was verified in the following way (Palmer (1995b)): In the middle of the low tide samples of the diatomes were transferred from the beach to the laboratory for 11 days and kept in continues light of 1100 lux and constant temperature of 18°C. In the following days the number of algae at the surface was determined in two hour intervals and plotted as a curve (red curves in figure 2.3). The highest values were found at times of low tides at the beach (lowered line of the blue curve). Although the algal cultures were in the laboratory, they exhibited a tidal rhythm. This indicates the existence of an internal tidal clock.

However, it might have been that a daily clock has driven this rhythm and its period length was incidently of the same length as the period of the tides. Therefore another experiment was performed, in which instead of continuous light a 12 hour light period and a 12 hour dark period alternated. In the case of a true tidal clock, which is not synchronized by the light-dark-cycle, the 24.8-hour rhythm should continue. That is indeed the case, as shown in figure 2.4. In spite of the daily light-dark cycle the maximum of the curves is delayed each day by 0.8 hours and follows the pattern of the tides.

But the *Hantzschia*-alga contains also a circadian clock. It allows the algae to migrate to the surface only during the light periods. In the dark it prohibits this migration. A model of this cooperation of a tidal clock (with two maxima per day which are 12.4 hours apart) and a circadian clock shows figure 2.5.

In long summer days one can notice occassionaly that the diatomes migrate twice per day to the surface (figure 2.6). That happens if a low tide occurs in the morning and the second low tide before the night, but in both cases in the light. A few days later the algae accumulate only in the morning on the beach. The low tide in the evening occurs now in the dark and the daily clock does not allow the upward migration. This daily clock is a *circadian clock*, since the behaviour can be observed also in algae kept in continuous light in the laboratory.

To sum up, this tiny alga possesses an internal clock which helps to adapt to the tides, and additionaly an internal daily clock, which programs the migration of the

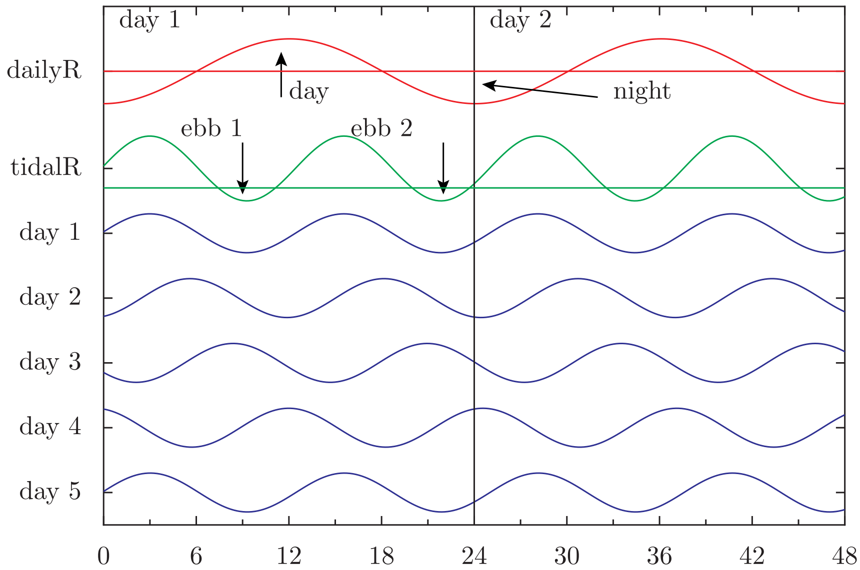

Figure 2.5: *Model of vertical migration of the diatome* Hantzschia virgata *in the day-night-cycle. A tidal clock (blue) with two maxima per day (with 12.4 hours distance) is influenced by a daily clock (red). The tidal clock induces migration of the algae to the surface only when the daily clock allows it (green part of red curve). That is the case, if the daily clock is in its light-liking phase (normally the day, but also in continuous light, see text and figure 2.6). The lower part of the figure shows the low tide (lowered part of the blue curves) and high tide (higher part of the blue curves). They occur each day 48 minutes later. After Palmer (1995b).*

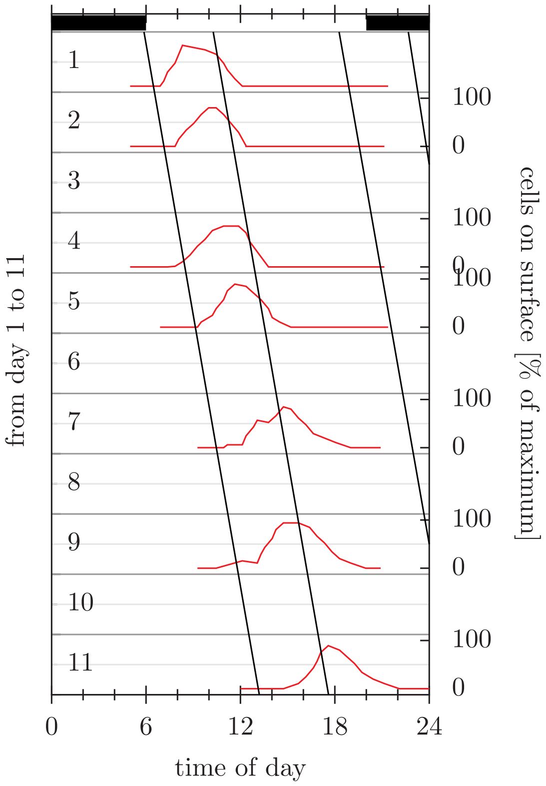

Figure 2.3: *The vertical migration of the diatome* Hantzschia virgata *is shifted with the tides. In the middle of the low tide (uppermost curve, lowered blue line in the morning -day is marked white, night is marked grey) samples of the diatomes were transferred from the beach to the laboratory for 11 days under constant conditions (Continuous light of 1100 lux, temperature 18°C). In the following days the expected low tide (lowered part of blue line) was entered (on the 10th and 11th day in the morning* and *in the evening). Each day the number of cells is plotted (red curve) in percent of the daily maximum. On the 3rd, 6th, 8th and 10th day no samples were checked. The red curve follows the times of low tide at the beach, that is, each day 48 minutes later. After Palmer (1995a).*

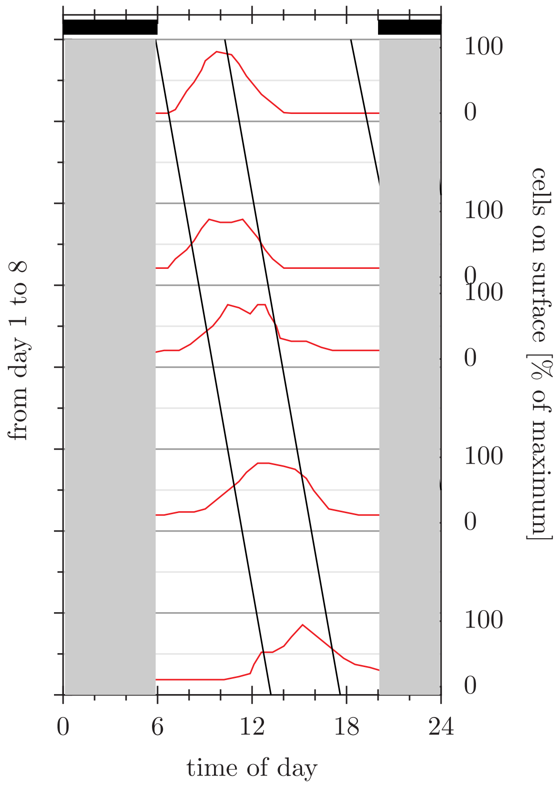

Figure 2.4: *Vertical migration of the diatome* Hantzschia virgata *in a day-night cycle. In the middle of the low tide (uppermost curve, lowered part of blue curve) samples of diatomes were transferred from the beach to the laboratory for 8 days and kept from 6 to 20 o'clock in the light and from 20 to 6 o'clock in the dark (no checks were made on the 2nd, 5th and 7th day). In spite of the daily light-dark cycle the maximum of the curves was delayed each day by 48 minutes, thus following the low tide pattern (lowered part of blue curves). We are thus dealing with a true tidal rhythm which is not influenced by the light-dark cycle. After Palmer (1995a).*

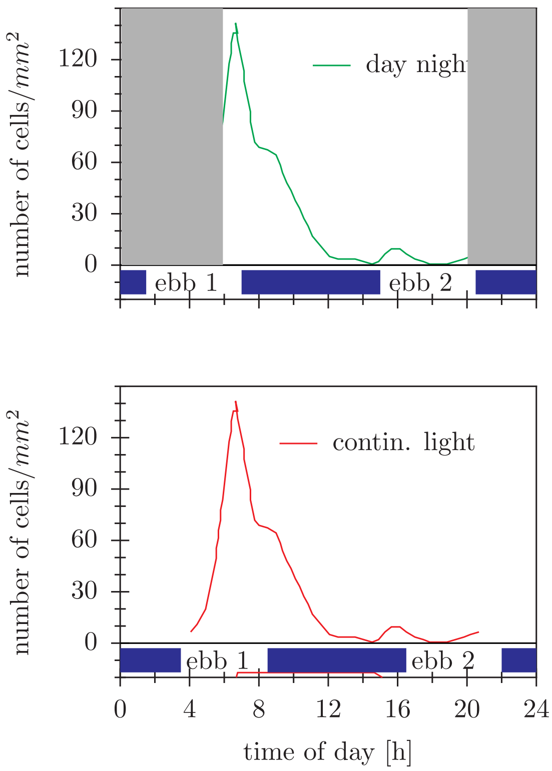

Figure 2.6: *The diatome* Hantzschia virgata *shows in longdays (in the summer, upper part) and in continuous light (lower part) occassionaly twice per day a vertical migration. This happens only, if the daily clock allows in both tidal phases, low tide 1 and low tide 2, to migrate. After Palmer (1995b).*

alga to the day.

The results of Palmer and his coworkers have been found to apply also to another diatome, *Pleurosigma angulatum*, (figure 2.1). This diatome inhabits the tidal zone of the Menai Straits in North-Wales. They too show the tidal rhythm in continuous light for at least eight days (Happey-Wood and Jones (1988)). Perhaps you will find also such a rhythm in algae at the beach?

2.2 A virtuoso Isopode

The diatome *Hantzschia* turned out to be a true master in its ability to adapt to its habitat at the sea. It is, however, outshown by the beachhopper *Excirolana chiltoni* (figure 2.7). The activity pattern of this virtuoso from the Californian coast is astonishingly well adapted to the tidal pattern of the coastal waters (figure 2.8 and 2.9). During high tide the animal is

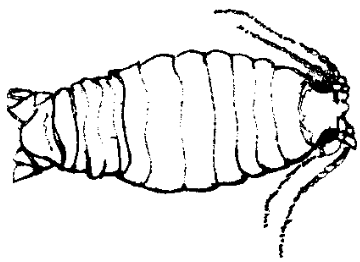

Figure 2.7: Excirolana chiltoni *is a beach-hopper from theCalifornian coast.*

buried in the sand, wheras during high tide it swims around in searching for food. The amount of activity depends on the hight of the tide. This hight changes, however, at the Californian coast in a rather complex way daily and on following days (so called mixed semi-diurnal tidal pattern).

The natural behaviour of the animals can be observed also in the laboratory in Petri

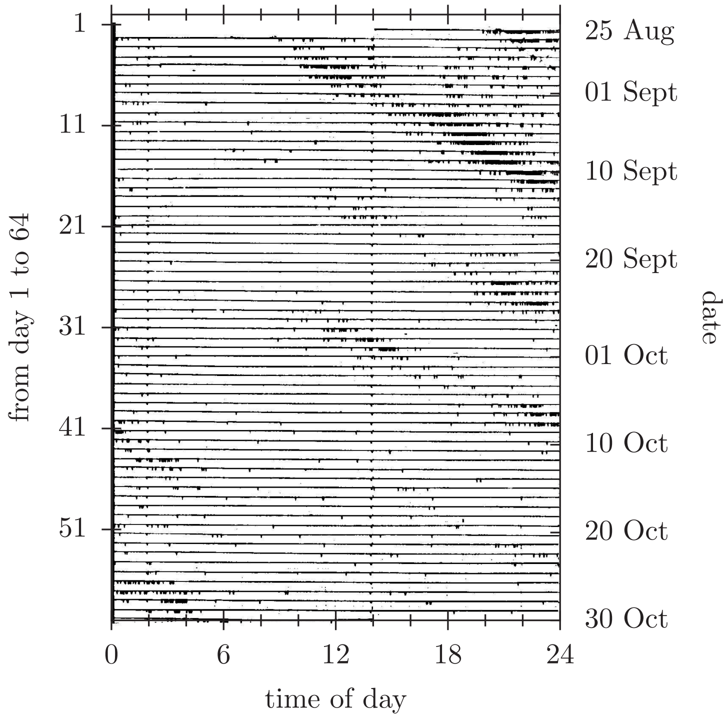

Figure 2.8: *Activity pattern of the swimming behavior of a beach hopper* Excirolana chiltoni*, a 'virtuoso' isopode from the Californian coast. The actogram represents the daily activity of an animal (consecutive days 1 to 65 below each other). After Enright (1972).*

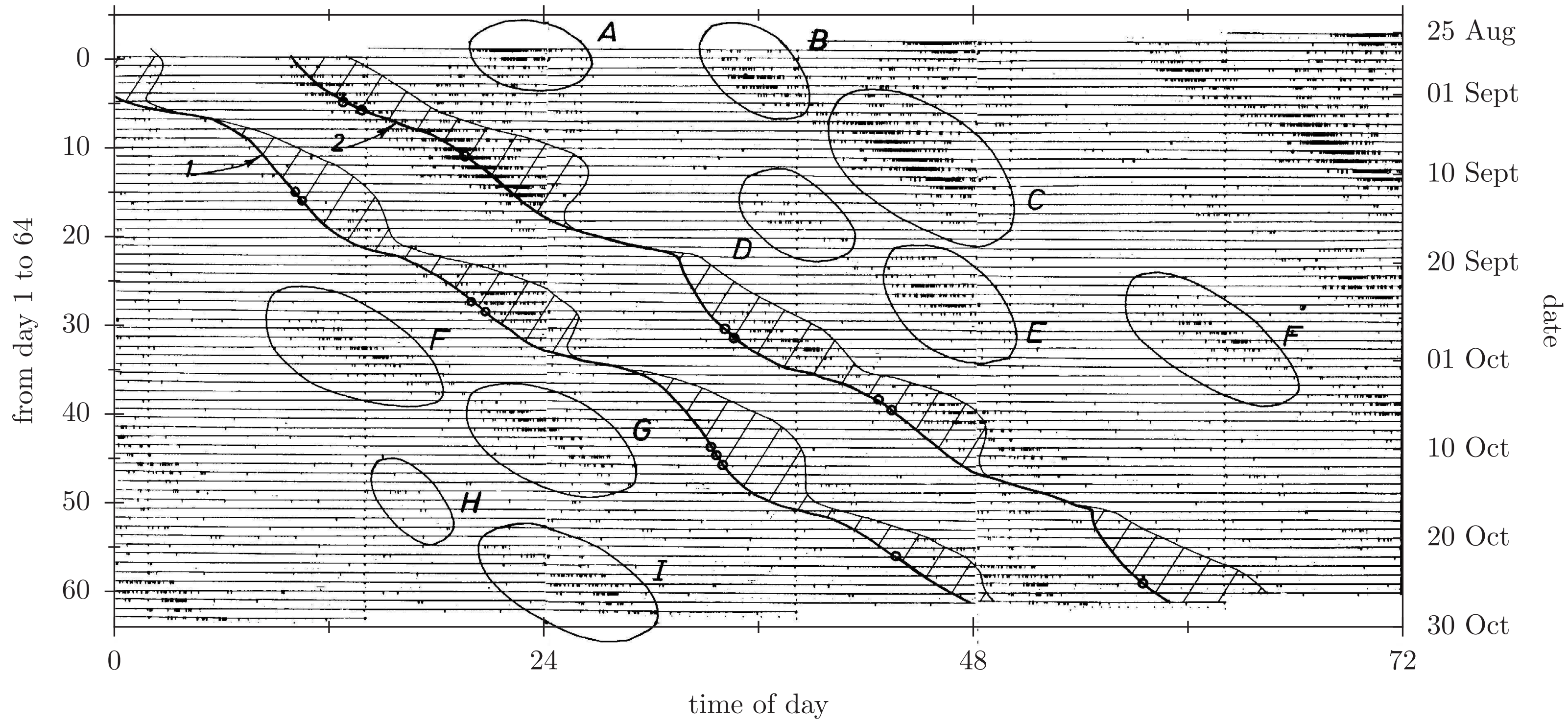

Figure 2.9: *The activity pattern of the swimming behavior of* Excirolana *from figure 2.8 has been duplicated, so that day 1 and day 2 are in one line, day 2 and day 3, day 3 and day 4 and so on. Line 1 connects one of the daily spring tides and line 2 the second daily spring tide. The small dots mark the days with maximal spring tide. The obliquely marked areas represent for each day the tide heights. The circled parts A to I of the actogram correspond to increased activities and correlate well with the tidal patterns as indicated by the lines 1 and 2 and the hedged areas. After Enright (1972).*

dishes containing sand and sea water. Even here the beach hoppers imitate the complex tidal pattern by using their internal clocks and their rest and activity follow it quite accurately (figure 2.8 and 2.9).

One could argue, that perhaps even in the laboratory a time cue is present, from which the animals get informations about the current tidal state. This is, however, not the case, since the activity rhythm in the laboratory steps slowly out of phase with the tidal rhythm.

In the biotop at the beach the animals, in spite of their internal tidal clock, have to perceive and use time cues of the tides which synchronize their endogenous rhythm. Candidates of time cues are pressure differences due to the periodic flooding of the animals or differences in the concentration of chemicals such as salt during the tides. Other candidates are temperatur differences or water turbulences. The light-dark-cycle, however, should not synchronize the tidal rhythms: It would set the animals to 24 hours and not to the necessary 12.4 hours or 24.8 hours.

Experiments of Enright have shown, that in *Excirolana* the water turbulence is a time cue. If the dishes are shaken in a tidal pattern with wave simulators (mechanical shaker or magnetic stirrer, Klapow (1972)) the animals are synchronised to a 12.4 hour rhythm. The length of the shaking period determines the pattern of the rythm: If a longer and a shorter stimulus are given 12.4 apart from each other, the longer stimulus leads to a stronger activity bout as compared to the shorter stimulus (figure 2.10).

Delays occur immediately, advances after more than 2 transient cycles. The bimodality of the actograms is amplified, if the shaking occurs in the middle of the two activity periods.

The curve shows two peaks per day (Enright in DeCoursey (1976), see figure 2.11). Enright interprets the bimodal curve as a bimodal circadian rhythm synchronized by the tides. Other researchers assume, that a tidal rhythm is responsible for the two peaks per day, and some of them believe that we are dealing with circalunidian rhythms (discussed on page 112 of Palmer (1995b)).

If the animals are not shaken for some time and than exposed to a stimulus (during two hours every minute for ten seconds), the tidal rhythm is phase shifted. Amount and direction of the phase shift depends on the phase in the tidal rhythm at which the animals were shaken. The strongest shifts occur at phases where the animals do not expect any water turbulence according to the build-in tidal clock. No reaction is found at phases where the animals swim around heavily, that is at high tide. In this way the animals are synchronized with the tides. Enright has shown the results of such experiments in a curve (figure 2.11).

An important result of these studies was, that the curve representing the response to single turbulence stimuli showed two maxima per day (Enright in DeCoursey (1976), see figure 2.11). Enright interpreted the curve with two peaks as *one* circadian rhythm, which is synchronized by the tides to 24.8 hours. Other scientists, however, believe, that one is dealing with a tidal rhythm which is synchronized by the tides to 12.4 hours. More likely is a third hypothesis, according to which one is dealing with *two* 'circalunidian' rhythms. Each rhythm has a period length of 24.8 hours[1], but running 180° out of phase: At the maximum of one rhythm the second one has its

[1]therefore the name 'circa-lunidian': corresponding to a moon-day (luna (latin) moon, dies (pronounced di-es) day)

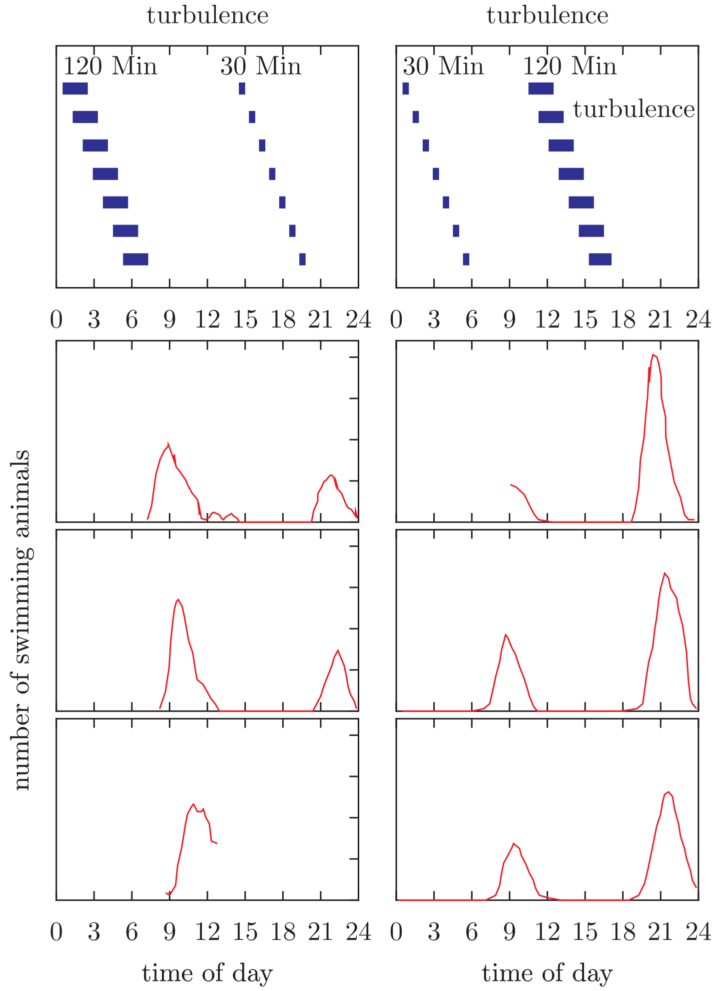

Figure 2.10: *In* Excirolana chiltoni *a long shaking period (120 minutes, blue bars at top) was followed 6 hours later by a short shaking period (30 minutes) (upper left part of figure). The swimming activity of the animal was measured afterward under constant conditions without shaking periods. A swimming pattern as shown in the lower left part with high activities and 6 hours later with smaller activities was obtained. If, however, first a short and afterward a long shaking period was administered (right upper part of figure), a period of smaller activities is followed 6 hours later by a period of high activities (right lower part of figure). The pattern of the tidal rhythm is thus reflected by the activity pattern. After Klapow (1972).*

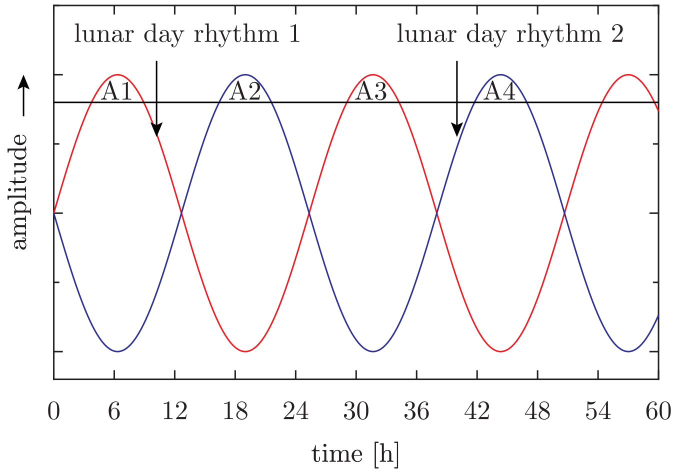

Figure 2.12: *Model of tidal clocks which are used by the* beach hopper Excirolana *to adapt to the tides. Two moon-day-clocks (red and blue curve) are running, each with a period length of 24.8 hours, but shifted against each other by 12.4 hours. Together they lead to two activity maxima per day (A1 and A2 respectively A3 and A4 on next day, A=activity during the parts of the curve which are beyond the threshold at the amplitude marked by the horizontal line), which are seen in figure 2.10*

minimum (figure 2.12). In favour of this hypothesis is, that one of the maxima dissappears occassionaly and comes back again without influencing the other rhythm.

A well designed clock is not influenced by different temperatures. This is also the case in the tidal clock of *Excirolana chiltoni*. It is temperatur-compensated.

2.3 Tidal rhythms in tree trunks

Tidal rhythms are not only found at the shores of the oceans, but also in trees on the mainland. According to Zürcher et al. (1998) the diameter of logs of wood change parallel to the gravimetric tides in the inland (Switzerland). Figure 2.13 shows in its upper part as a red curve the changes of the trunk diameter and in the lower part as a blue curve the tidal curve as changes in gravity. Both curves run parallel to each other.

This was found in young trees, and even under constant temperature, humidity and light period. The rhythms were claimed to be present even in trunk pieces which were cut off from the tree top and the root system. They can be recorded in such isolated pieces for months as long as the cambium[2] is still alive. The time course of the changes is identical in different trees. The rhythms are observable also if the logs are kept in continuous light or continuous darkness. If the light-dark-cycle is inverted (light during the night, darkness during the day) the rhythm stays unchanged. The rhythm is found also during the winter, while the trees are in a dormant state.

This sounds quite mysterious. However,

[2]the cambium is a tissue layer between the inner wood and the external bark and is responsible for the thickening of tree trunks

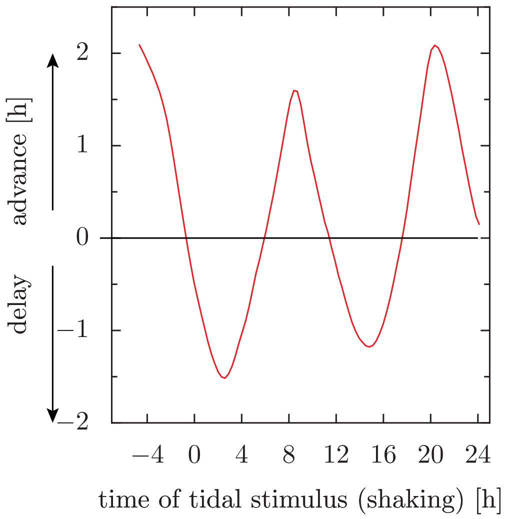

Figure 2.11: *How* Excirolana *reacts to turbulence: The swimming activity of* Excirolana chiltoni *was recorded in individual animals or groups of animals for three to four days in freerun. Than the animals or groups experienced a tidal stimulus by shaking them at different phases of the cycle (abscissa) for two hours (every minute for 10 seconds). Afterward the swimming activity was recorded again under constant conditions. The phase shifts of the rhythm due to the stimuli were plotted as advance (y-axis upward) or delay (y-axis downward) in a phase response curve. After Enright in* DeCoursey (1976).

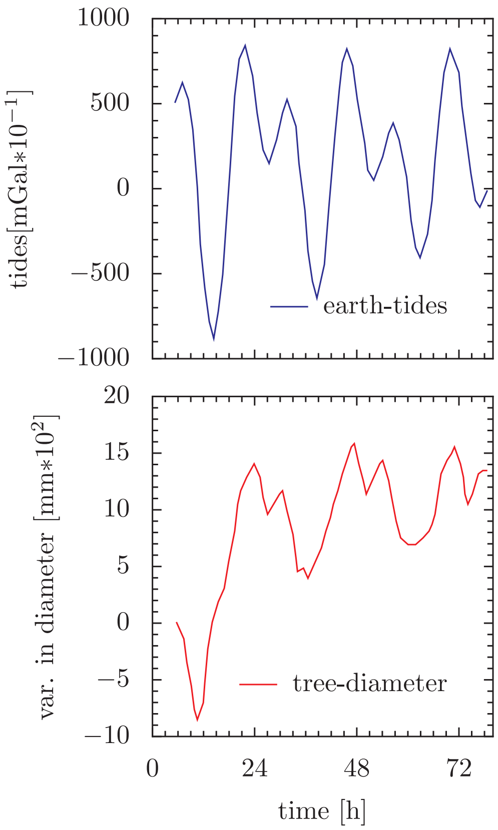

Figure 2.13: *The diameter of a log of wood (red curve) changes during the course of days (x-axis) parallel to the gravimetric tides in the inland (Switzerland, blue curve). After Zürcher et al. (1998).*

tidal forces do indeed exist in the solid earth. The moon affects not only the body of water in the oceans, but also the mass of the solid earth. As a consequence water is lifting and sinking, amounting to about 20 cm. In drill holes the water level does indeed fluctuate in a tidal rhythm, and the amount of water of springs is influenced by the tidal rhythm.

How the diameter of logs can be changed by the tidal force is not yet known. It is assumed that water from the interior of the cell enters the cell walls and the external part of the wood. This transportation might somehow be affected by these forces.

2.4 Chronogeology: What daily, monthly- and annual rings in fossils tell us

Everybody knows the annual rings of a tree. They arise because the thickness of tree trunks increases stepwise. During the spring and summer the growth conditions are favorable. The cells which later form wood are large. In the fall, however, they are smaller and during the winter there is no growth (figure 2.14).

Annual rings are observable also in shells of clams and snails. The growth of the shells reflects annual fluctuations of the temperature in oceans. In the same way as in tree trunks the age of a clam can be determined by counting the annual rings. However, since the shell of a clam shows in addition a daily growths pattern, the number of days per year can be counted. As expected, present-day clams show 365 daily rings per year.

The conditions in the sea fluctuate, however, not only in an annual rhythm. Fluctuations in the depositions during the growth of shells occur also during the course of a month and/or during the course of fourteen days (that is with the high and low tides). This amounts to 29.17 days per month in shells of the marine clam *Mercennaria mercenaria*.

Such studies were performed also in fossil shells of snails and other marine organisms and stromatoliths (figure 2.15). It turned out that the number of daily depositions per month were larger in earlier ages of the earth. The same was found for the number of daily depositions per year. The physics of celestial bodies tells us that the orbit of a planet, which is escorted by a sattelite such as our moon, slows down slowly, because of frictions. They result mainly from the tides of the water masses. As a consequence, the moon moves slowly away from the earth.

It was indeed found in fossil shells that a month consisted in earlier ages more days. Instead of 29.17 nowadays there were 18 million years ago 29.40 days, 46 million years ago 29.82 days, 72 million years ago 29.92 days, 305 million years ago 30.07 days and 510 million years ago 31.56 days. The number of days per year increases too, if the daily depositions per year are determined.

If the values are plotted in a curve (figure 2.16), it turns out, however, that these changes did not proceed uniformly. Instead there were ages at which the changes occurred fast (for example in the last 100 million years and 300 to 500 million years ago). This strange finding is explained with the expansion of the oceans. If they are large, the tides are more pronounced and the frictions are stronger. The orbit of the earth is slowed. In the last 100 million years the Atlantic was quite extended, and 300 to 500 million years ago the pacific was very large. In the interposed time the Atlantic was smaller.

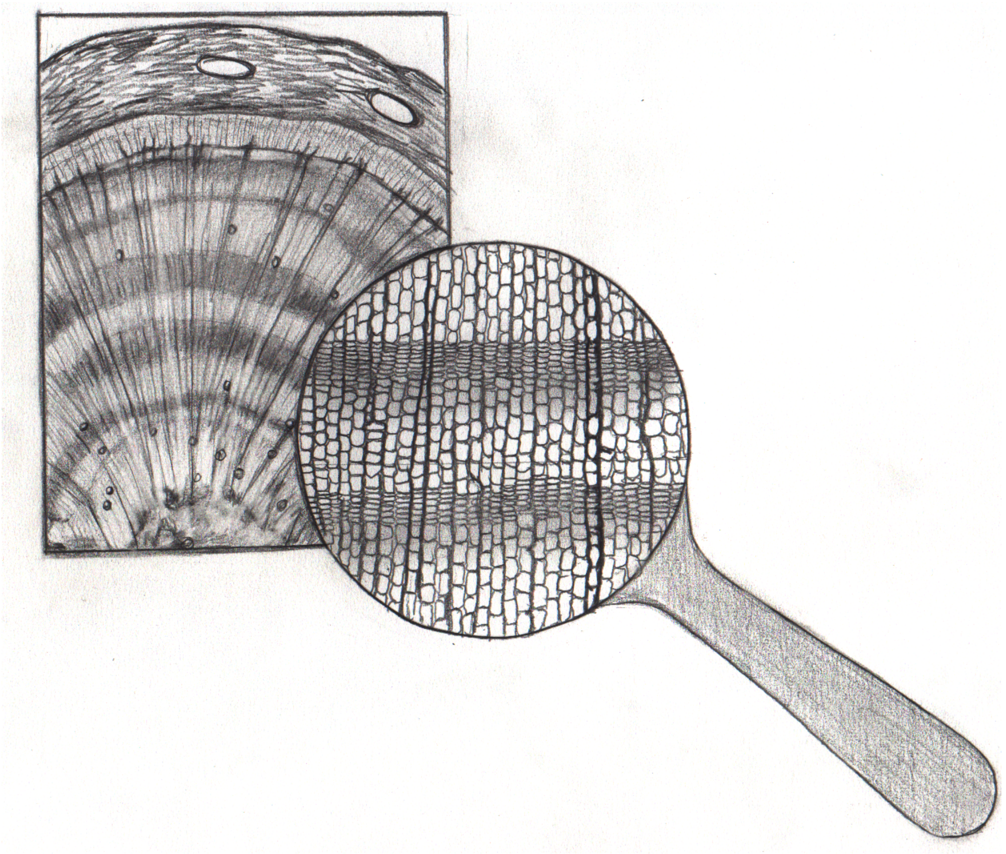

Figure 2.14: *Piece of a trunk of a four year old pine. Four annual rings with spring- and late wood. In the center mark, from which mark rays radiate. Cambium, bast and bark at outer part. At higher magnification the early wood (large cells with thin walls, left) and the late wood (small cells with thick walls, right) during the course of three years. Drawn by Mareike Förster*

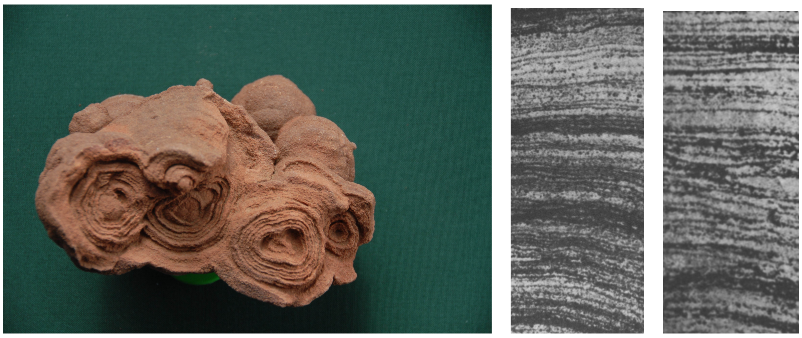

Figure 2.15: *Left: Fossil stromatoliths from Marocco, Hamada du Guir south-southeast of Erfoud; kindly supplied by Hans-Ulrich Seitz, Tübingen. Center and right: Monthly and fourteen day growth pattern in stromatoliths (fossil, mostly lime stone sediments produced chiefly by cyanobacteria partly more than 3.5 billion years old). Left: The monthly rhythm is more pronounced. Right: The fourteen day rhythm is more pronounced. Growth direction to the top of the figures. Length of the left preparation 15mm, of the right preparation 7.5 mm. After Pannella et al. (1968) /monatsringe*

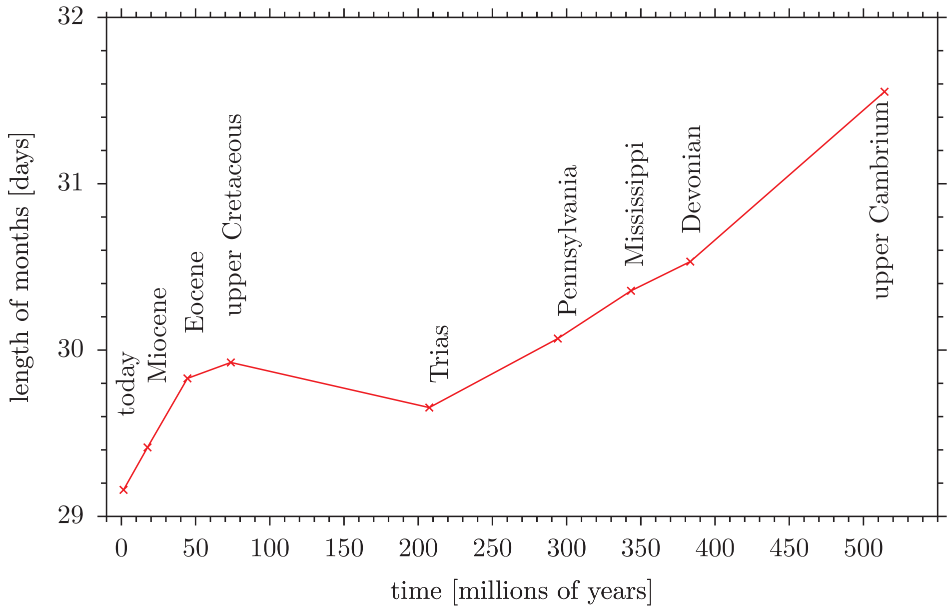

Figure 2.16: *From the monthly growth patterns of fossil clam shells the number of days per month was determined and plotted against the geological age. Ages with small changes (100 to 300 million years ago) alternated with ages with larger changes (the last 100 million years and 300 to 500 million years ago). After Pannella et al. (1968)*

3 Fourteen day rhythms

Low tide and high tide wax and vane during fourteen days, due to the constellation of earth, moon and sun. Spring- and neap tides arise. Some organisms of the sea costs have adapted to these extreme tides. Three examples are presented, the spawning of a fish, the release of larvae of a land crab, and the eclosion of the one hour midge Clunio.

The differences between low tides and high tides fluctuate with the moon. At spring tides earth, moon and sun are lined up. Therefore sun- and moon forces act combined and the high tides are especially high, the low tides especially low. They are called spring tides. At half moon the moon is perpendicular to the line of earth and sun. The gravitational forces of the moon and the sun affect the earth from different directions and the forces are smaller. The resulting tides are called neap tides (see figure 1.2). The tides of the seas (and of the land masses!) show therefore fourteen day variations in their strength. A number of organisms at the coasts have adapted to these rhythms.

We will get to know fourteen day rhythms in three examples. First the spawning of the grunion at the Californian beach is presented. In the land crab *Sesarma haematocheir* larvae are liberated from the mother in a fortnight rhythm. In populations of the one-hour midge *Clunio marinus* midges eclose every forteen days at certain times which allow the animals to reproduce and to lay eggs. There is a movie available for this rhythm (Neumann (1973)). Another movie was produced by Walker (1964) on the fourteen day rhythm in the grunion *Leuresthes tennis* in California. Both movies can be lent out by schools from the Institut für den wissenschaftlichen Film in Göttingen (Germany).

3.1 Grunions spawn at the beach

Once in a year a huge pageant occurs at the coasts of California: The grunion fish *Leuresthes tennis* spawns. With the high tide thousands of fish arrive at the beach, The females bore their tail into the wet sand and deposit with shivering motions their eggs deep in the sand. During this time they are surrounded by males which try to fertilize the eggs with their 'milk'[1] (figure 3.1).

The fertilization of the eggs is in these fishes restricted to a small period of time. This increases the chances of fertilization a lot. Furthermore the spawning occurs at a time from which on the high tides are getting higher from day to day. In this way the eggs are covered by more and more sand (figure 3.2 top). Forteen days later they are washed out by the falling high tides. Exactly this time is needed by the embryos in the egg shells to develop into a baby fish. The last high tide washes finally the eggs out of the sand (figure 3.2 bottom). They are churn and this mechanical shaking makes the baby fish to eclose out of the egg shell. The high tide pulls the young

[1] that is the name of the sperms in fish

fishes in the sea. Many of them are eaten by predatory fish, but enough survive to keep the species alive.

Figure 3.1: *A grunion fish lays its eggs in the wet sand of the Californian beach. A male encircles it and fertilizes the eggs with its 'milk'. Drawn by Mareike Förster from a picture in Geo, December 1984*

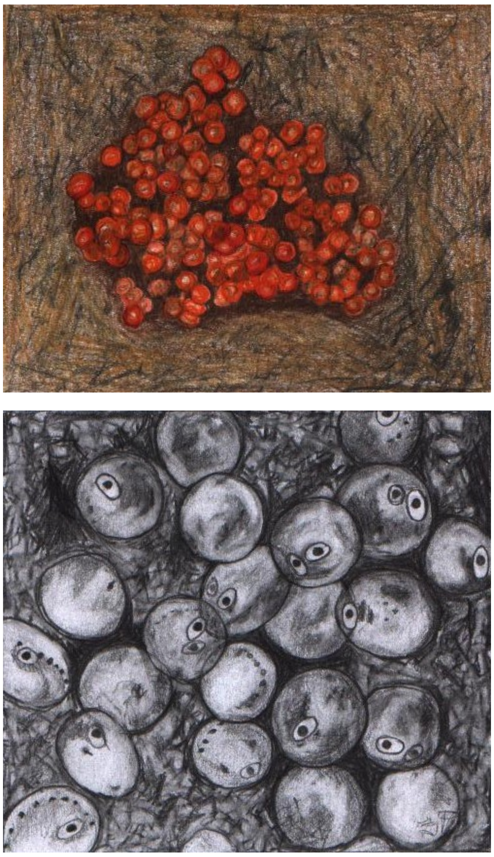

Figure 3.2: *Grunion fry immediately after oviposition into the wet sand (top) by the female and (bootom) before eclosion of the baby fish -the eyes are visible. Drawn by Mareike Förster from a picture in Geo, December 1984*

3.2 Sending the children every fortnight into the sea

Sesarma haematocheir is a terrestrial crab which is common in Japan. Different populations live in quite diverse habitats. But all of them must take care, that the lar-

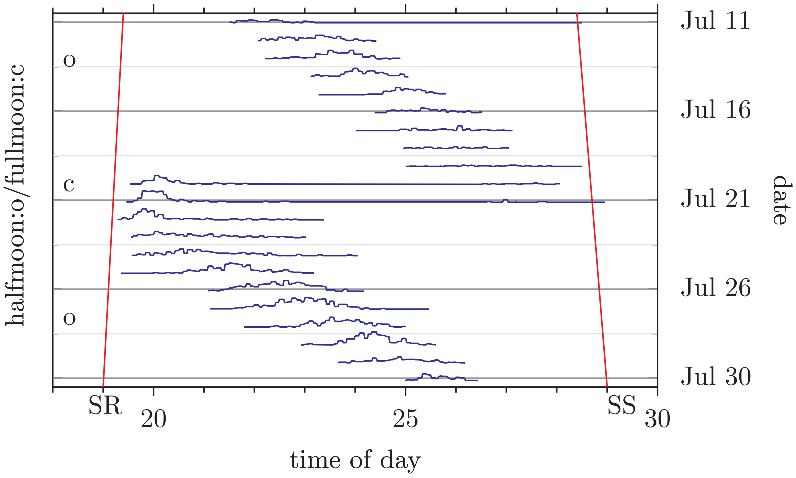

Figure 3.3: *Release of zoea-larvae by female weibliche terrestrial crab* Sesarma haematocheir. *For each day (horizontal lines) the number of females, which released larvae, was plotted as a curve (blue). Sun rise (SR, first blue line) and -set (SU, second blue line) and moon rise and -set (red curves) are shown together with the first and second high tide of the day. Newmoon •, fullmoon o, half moon c. After Saigusa (1986).*

vae are transported to the sea. A longer stay in fresh water would be fatal. One of the populations of this species live as adults in the mountains above the Ogamo river close to Kyoto. The crabs copulate during the summer. The fertilized eggs are discharged and stick to hairs at the ventral side of the abdomen of the females. After the larvae have reached the zoea-stage[2], the mother crab heads in the late afternoon for the river. At the time of twilight it enters the water, clings to a stone and beats its abdomen strongly up and down. This induces hedging of the larvae out of the egg membrane. They swim the final 100 meters of the river to its mouth and develop there in the salt water (Saigusa and Hidaka (1978)). The larvae are only discharged at the time of dusk and especially at days around full- and new moon (figure 3.3). Trigger is the light-off signal. But what controls the fourteen day rhythm? To clarify it, experiments were performed by Saigussa in Japan.

[2]typical larval form of most of the Zehnfüßer-crabs with floating appendices

If the animals are kept in a 14:10 hours light-dark change at 23^{0}C in the laboratory, the fourteen day rhythm stays for about six cycles. It is thus controlled by a fourteen day clock which turns once in a fortnight. In a further experiment artificial moonlight was given in a 14:10 hours light-dark change, each night by 48 minutes later, as would occur in nature. However the artificial moon cycle was shifted against the natural one by seven days (figure 3.4, Saigusa (1986)). It turned out that the artificial moon light synchronized the rhythm, under which the zoea-larvae were discharged into the water.

3.3 They danced only an hour: *Clunio*

The small one-hour midge *Clunio marinus* (a marine chironomid) is found at the European coasts of the Atlantic (a population is also found in the Baltic sea; but it behaves differently). The larvae live in algal mats in the lower most range which is influenced by the tides. Briefly before a spring tide the mature larvae pupate. Three to five days later the males eclose at the local low tide. They fly over the area, which has fallen dry until they have found a female. They are only able to eclose from the pupal case with the help of a male (figure 3.5). They are wing-less and carried by the males to favorable places, where the fertilized eggs are deposited as a jelly package on red algae. Their life task is fullfilled, the

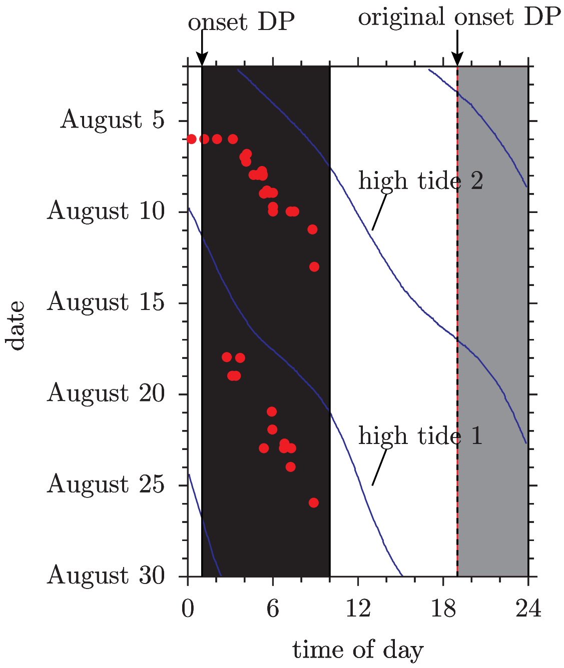

Figure 3.4: *Discharge of zoea larvae by female terrestrial crabs* Sesarma haematocheir. *The light-dark change was delayed by 6 hours as compared to the control (not shown). Whereas the control animals would discharge the larvae during the first high tide (black curve, marked high tide 1) or during the second high tide (high tide 2), they are now delayed by six hours (see red circles). Since tidal rhythms are not synchronized by the light-dark change, the delayed circadian clock must have shifted the moon clock. After Saigusa (1986).*

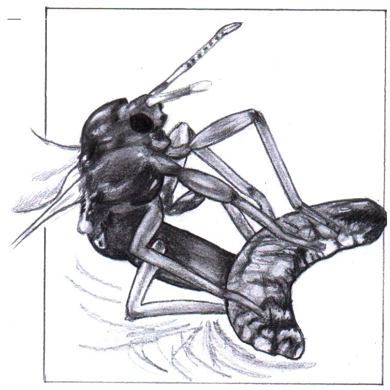

Figure 3.5: *A male of* Clunio marinus *(chironomid) copulates with a female (which are wing-less), after having cut open its pupal case with its (especially large) hypopyg of the abdomen. Drawn by Mareike Förster after Caspers (1951).*

animals shrivel and die shortly afterward. That is the reason they are called one hour midges. The males do also die after having fertilized the females, and the corpses are washed away by the flood.

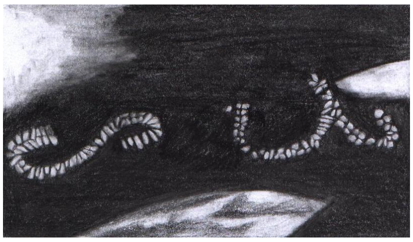

Figure 3.6: *An egg package of the one hour midge* Clunio marinus *was deposited by a female on a mat of red algae at neap tide. At that time the algae are not covered by water. Drawn by Mareike Förster after Geo December 1984.*

These insects use a forteen day clock for eclosing at the neap tide. At that time the water level is especially low. A daily clock ensures that the animals eclose at a certain time of the day when at the habitat of the population low tide prevails. This is for the population at the coast of Heligoland the evening. This ensures that the animals eclose and mate at times when the substratum has indeed fallen dry. The tidal patterns at the coasts of the Atlantic and of the North Sea are shown in the book of Endres and Schad (1997). Each day the low tide and high tide comes by 48 minutes later. Every 14 to 15 days the same situation of an extreme low tide repeats at the coast which is favorable for the reproduction of the animals. To understand the timing conditions correctly, we should have a look on details of the timing.

As a timing mechanism the animals use a circadian clock and a fourteen day clock (red squares in figure 3.7). Both are internal clocks, but they have to be synchronized by external time cues. Zeitgeber for the circadian rhythm is the light-dark cycle, Zeitgeber for the fourteen day rhythm is in southern populations (France, Portugal and Spain) the moon light. Northern populations however use another Zeitgeber. The summer nights in the north are too short and the moon is too low at the sky, to be able to act as a Zeitgeber. Instead water turbulences (50-200 Hz) are used which are produced by the incoming high tide. The change from stronger to weaker turbulence is especially effective. This change is perceived by mechano-receptors. They have to be stimulated in *Clunio* for at least 6 hours, optimally for 8 hours. The circadian system is sensitive for the change at daytime. It serves as a filter in the central nervous system and controls the fourteen day oscillator. This event occurs once only every 15 days.

Clunio exists in several coastal populations (figure 3.8). The adults of all populations eclose at neap tide (full moon or new moon). We are dealing with geographically isolated time-races (figure 3.9). Depending on the location and the neap tides at these particular coasts, the animals eclose at different, but specific times of the day. The offsprings of parents from different populations eclose at times which lie between the eclosion times of the parents. For these differences in eclosion time not one, but two or three genes are responsible.

The physiological events underlying this behaviour are not well understood. Neurosecretory cells in the brain secret at certain times hormones, which determine the time of eclosion during the day.[3]

Such physiological timing mechanisms (that is, clocks) couple physiological performance with a cyclic environmental factor. This time cue has to be reliable and the organism must be able to perceive it (needs receptors for it). The environmental condi-

[3] Similar to the eclosion of the giant silkmoth (Truman (1992)).

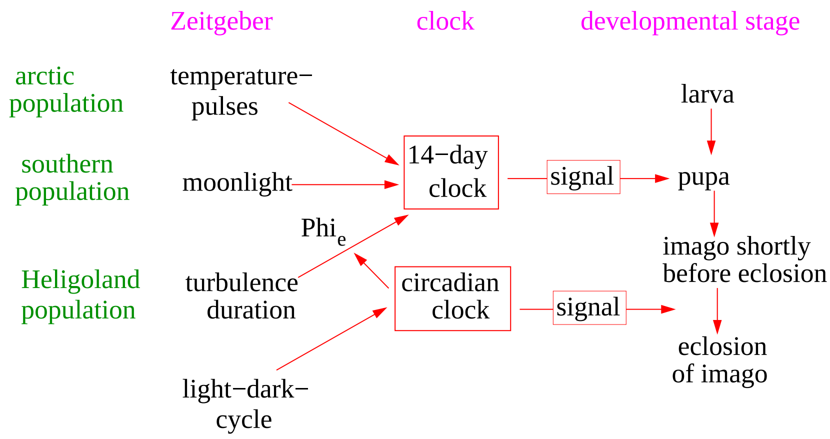

Figure 3.7: *In* Clunio marinus *pupation is controlled by signals of a fourteen day clock and eclosion of the imago out of the puparium by signals of a circadian clock. Zeitgeber of the circadian clock is the light-dark change, Zeitgeber of the fourteen day clock, depending on the population (green), the temperature change (arctic populations), the moonlight (southern populations) or the turbulence of the water (Heligoland population). Turbulence has to occur for some time at a certain time and to terminate at a sensitive phase Z (red) of the circadian clock, in order to synchronize the fourteen day clock. After Neumann (1976) and Neumann (1988).*

tions which are responsible for the selection of the various geographic varieties can be quite different. For the selection of the varieties in *Clunio* the daylight has a Zeitgeber function. It is the factor which acts immediately (also called ultimate factor). Selection factor for the proper diurnal phase relationship is, however the tidal cycle, which acts indirectly (also called proximate factor). In *Clunio*-populations in northern latitudes tidal turbulences and day-night-rhythms are the time cues. In populations of the south, however moon light and the day-night-rhythm are responsible. In addition non-oscillating timing systems are used which do not use a cyclic clock, but measure the length of time in the kind of a stop watch, for instance, whether the turbulence is longer than 6 hours. Arctic strains use an hourglass mechanism by measuring the temperature difference.

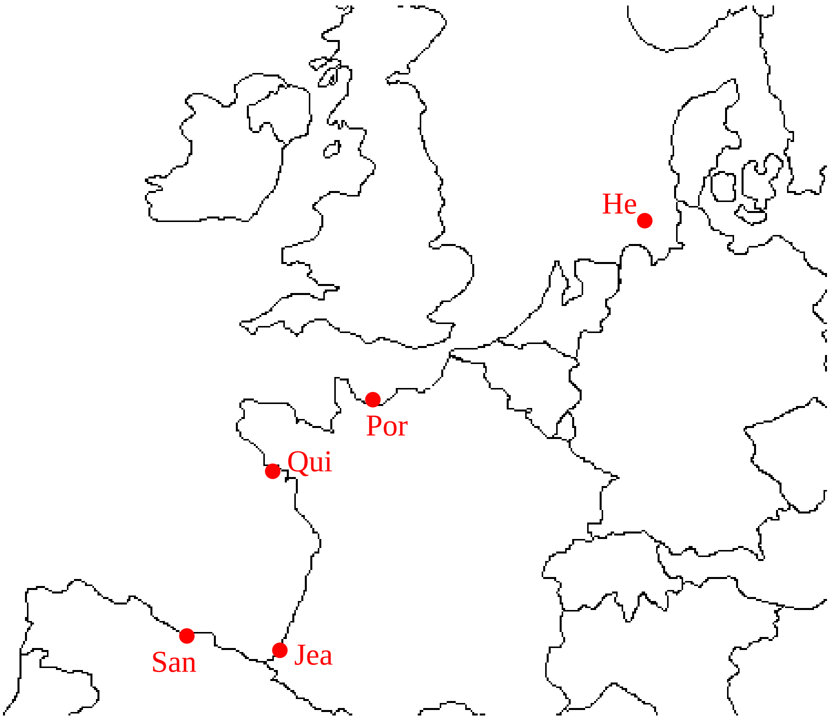

Figure 3.8: *The locations of populations of* Clunio marinus *collected from the coasts of the Atlantic and the North sea are shown (compare with figure 3.9). The collection places (German bay - Heligoland (He), Normandy - Port-en-Bessin (Por), Bretagne - Quiberon (Qui), Basque coast - St. Jean-de-luz (Jea) and coast of northern Spain - Santander (San)) are marked with red dots. The map shows furthermore the latitudes- (top) and longitudes (left) and the lines of time of high tides. These are lines of identical mean high tide differences in respect to the meridian passes of the moon in Greenwich. After Neumann (1966).*

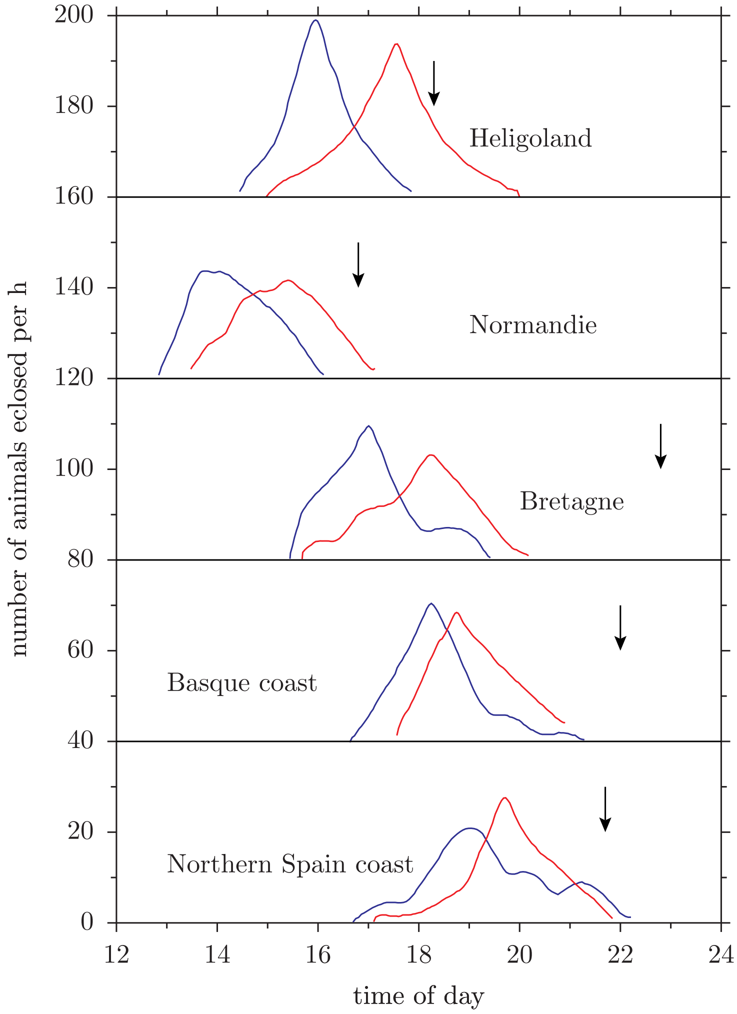

Figure 3.9: *The eclosion behavior in populations of the one hour midge* Clunio marinus *from the coasts of the Atlantic and the North sea are shown for males (red) and females (blue). It is in all cases a few hours before the local low tide (arrow with variation). For the collection localities (German bay - Heligoland, Normandy - Port-en-Bessin, Bretagne - Quiberon, Basque coast - St. Jean-de-Luz and coast of Northern Spain - Santander) see map, figure 3.8. After Neumann (1966).*

4 Monthly rhythms

Monthly rhythms with periods of 28 days are presented in the examples of the pit volume of the antlion and in the swarming of the palolo. Women menstruate in a rhythm of 26 to 30 days. The time of menstruation is, however, not correlated with the lunar cycle. This might have been the case in earlier times. In some primates of South America copulation and ovulation occurs during full moon.

We got to know in different organisms tidal rhythms and fourtnight rhythms. Organisms can adapt also to monthly rhythms. The moon reaches after 28 days the same phase (for instance full moon or new moon). If an animal wants to use the light of the full moon in order to induce certain physiological processes or behavioural events, a monthly clock with a period of 28 days would be useful. Such clocks do indeed exist. We will get to know some of them in the following. If you want to read more about it, check Endres and Schad (1997).

4.1 Pit excavation in a lunar rhythm

In some insects activity fluctuates in a monthly rhythms. The antlion[1] *Myrmeleon formicarius* (it belongs to the family Myrmeleontidae and the order Neuroptera) is an interesting example. The bright- to dark-grey coloured larvae (figure 4.1 left) build a pit in sand or sandy soils (figure 4.1 center). They select locations, which are protected against rain, but still sunny, such as escarpments, edges of the forests, or shrubbery. They can move only backward, because bristles at the body are directed forward. Jerkily they dig in the sand quickly and cast sand fast and far-flung away as soon as the head is below the sand. In this way they come deeper and deeper. Already after a short time the pit can be finished. It can be 5 cm deep with a diameter of up to 8 cm. The larva sits in the center of the pit. Only the mouth tools which are transformed to sucking pincers are beyond the sand. If sand trickles in the pit, it will be thrown out immediately. An insect, which slips in the pit is seized with the pincers. Poison is injected into the victim and it is sucked out. If an animal tries to escape the pit, it is bombarded with sand until it falls down again. If the winter is coming the larvae dig deaper into the soil. How long the larval stage lasts, depends strongly on the climate and the food. Normaly the larva hibernates for a second year. In May it stops feeding, spins a spheroidal cocoon with about 2 cm diameter and pupates in it. The adults (figure 4.1 right) eclose at the end of June to July.

The size of the pit of the antlion (figure 4.1) fluctuates during the course of a month. Around full moon they are large, a few days earlier small (figure 4.2). It is a true monthly rhythm, since it can be observed also in the laboratory under continuous darkness. To record the pit size

[1] called "doodlebugs" in the United States because of the meandering trails on its search for the location of its pit

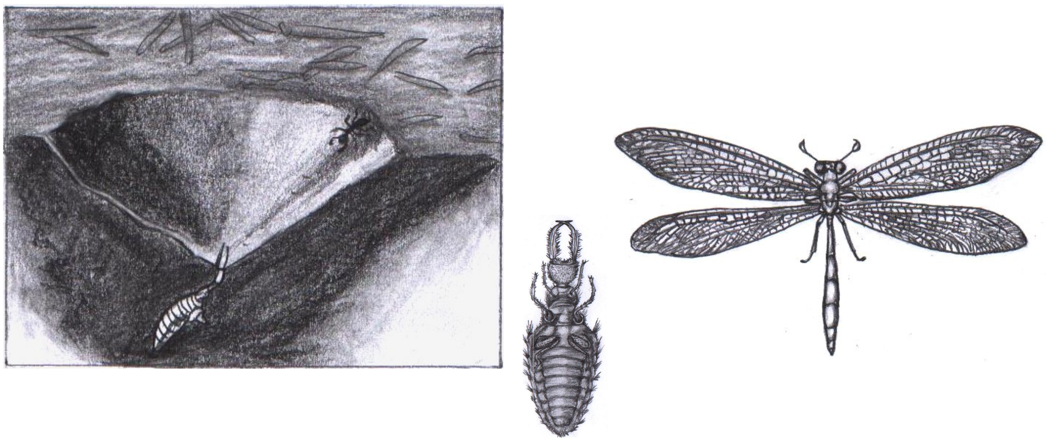

Figure 4.1: *Left: At the base of its pit the larva of the antlion* Myrmeleon obscurus *waits for bait. Center: with its large pincers it seized its victim and injects digesting juice into it. Later the liquidiced content of the bait is sucked in. The larva has no opening of the intestine. Only at the moult uric acid as a leftover of the digestion is excreted via the mouth. Right: The imago looks like a dragon fly, belongs, however, to the family of the neuroptera. Drawn by Mareike Förster after Hesse and Doflein (1914).*

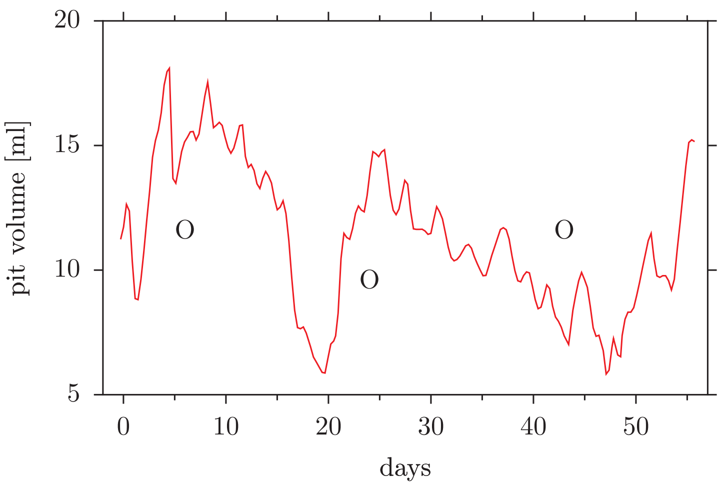

Figure 4.2: *Volume of the pit of the antlion* Myrmeleon obscurus *(neuroptera) fluctuates in a monthly rhythm. At times of full moon (open circles) the pits are much larger as compared to the days before. The curve represents the results of recordings of 24 larvae which were kept for 55 days in continuous darkness. After Youthed and Moran (1969).*

the nasty scientist, after having determined the volume, threw the sand back in the pit, which the bug had thrown out before. Thereupon the antlion started again to throw out the sand.

The eclosion of insects can occur in monthly rhythms. At the lake Victoria in Africa lives the African May fly *Povilla adusta*. It ecloses in the nights briefly before and after full moon, especially at the second day after full moon (figure 4.3). The adults live only one and a half hours. Therefore the animals have to eclose in a small time window in order to copulate. They do it during the short time when twilight[2] is lengthened by the full moon. During this time the mating flight and the copulation takes place. The rhythm is endogenous, since it continues in the laboratory.

Figure 4.4: *palolo worms live in coral reefs around the palolo-, Samoa- and Fiji-islands. The sexual products are discharged during the night seven days after full moon in October/November of each year and swim to the surface of the sea. The inhabitants of the islands catch them during the nights as delicious food. Drawn by Mareike Förster after Caspers (1951).*

4.2 How the moon offers the Samoan a feast

Since ages the natives of Samoa and other islands of the Southern Pacific celebrated a big feast in the fall when the palolo swarms. This polychet is an exquisite delicacy (figure 4.4 and figure at the begin of the book). The swarming of the 'Mbalolos', as they are called by the Samoans, occurs at a specific time of the year and is expected wishfully. Suddenly the sea is a swirling mix-up of palolo-posteriors. The boon is scooped from the water with baskets and prepared for the feast meal. The mbalolo is eaten either raw or wrapped up in fresh leaves as a special delicacy (figure 4.5).

The palolo *Eunice viridis* lives in huge numbers in coral reefs around the Palolo-Samoa- and Fidschi-Islands. It digs curved tubes into the corals. Its worm-like body is coloured bright green and up to 40 cm long (figure 4.6). Each year during October and November the sexually mature animals cast off their posterior parts ('epitok') containing either the sperms (males) or eggs (females). They swim to the surface of the sea and swarm there. This happens only two or three days after the third quarter of the moon and begins at a certain time after midnight. The exact time depends on the geographical position of the islands. At the most western island Tutuila it begins at 0:30 o'clock, at the more eastern islands Upolu and Savaii between 5:00 and 6:00 o'clock in the morning.

Normally most of the animals swarm briefly after the third quarter of the moon at the end of October. In November only a few animals swarm at the corresponding moon phase. If, however, the third quarter of the moon occurs *before* the 18th of October, the main swarming takes place in November.

This inhabitant of the sea swarms thus

[2] the lake Victoria is close to the equator, therefore the twilight is short

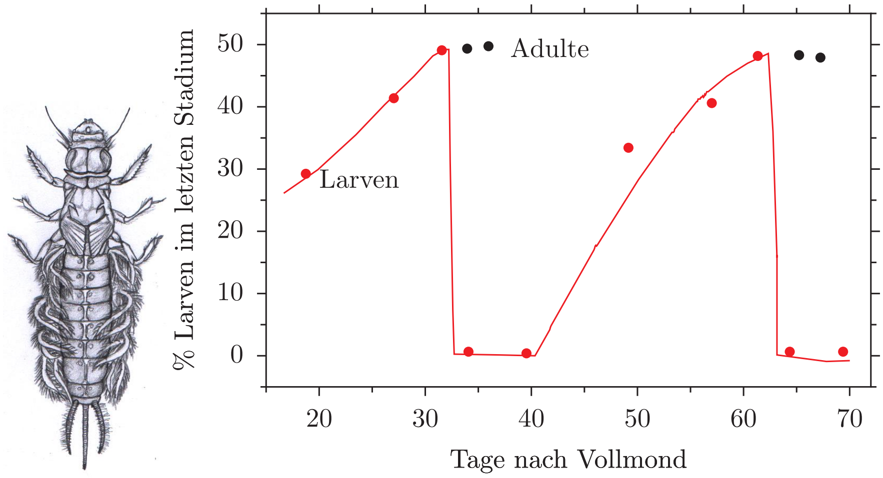

Figure 4.3: *African Mayfly* Povilla adusta *(adult: top) emerges in large numbers from the lake Victoria shortly after full moon. It is a monthly rhythm with a period length of about 30 days. Drawn by Mareike Förster after Corbet et al. (1974)*

at a very restricted time: Five to four days before full moon and only at two or three occasions in the fall (October/ November) and only at a certain time of day. If the animals would release eggs and sperms without such a 'time window', but continuously, it would have to produce 732 times as many eggs and sperms, in order to have the same chance to reproduce[3]. In this way the chances to fertilize the eggs are increased enormously (Hauenschild et al. (1968), Caspers (1951), Caspers (1984)).

There are numerous further examples for lunar rhythms. Here we mention only the Guppy fish. Its sensitivity towards yellow and violett light fluctuates during the course of a month by one order of magnitude (Lang (1970)). It is so far not known, by which time cue this rhythm is synchronized. Experiments preclude differences in air pressure and fluctuations of the air electricity. Micro-vibrations, fluctuations of the gravity and the earth's crust might be responsible.

4.3 Monthly rhythms in humans?

Menstruation[4] in women follow a cycle of about 26 to 30 days, with 29.5 days as an average. Since this period is close to the moon cycle, it was assumed that the menstruation cycle is synchronized by the moon. This is, however, according to several studies (Pochobradsky (1974)) not the case, although there are some hints, that in certain cultures and native tribes such relations do exist. A woman of the Yurok Indians from California reports, that in earlier times all non-pregnant, fertile woman of a household menstruated at a certain time dictated by the moon (Schlehe (1978), page

[3] 6 days instead of 365: a chance which is 61 (365:6) times higher, 2 hours instead of 24: a chance which is 12 (24:2) times higher, altogether a 12*61 = 732 higher chance

[4] menstruation is a bleeding of the uterus which lasts 3-5 days. The uterus mucous membrane (endometrium) is discharged

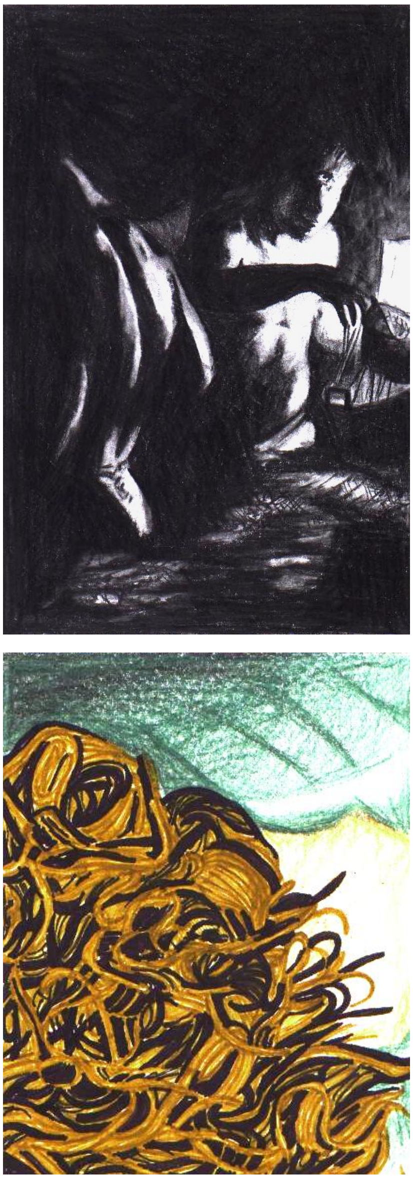

Figure 4.5: *During the swarming of the palolo a big feast is celebrated on the Palolo-, Samoa- and Fidschi-Islands. The 'Mbalolo', as they are called by the natives of the islands, is eaten raw or backed in leaves as a delicacy (bottom and figure at the begin of the book). Drawn by Mareike Förster after Geo 1984.*

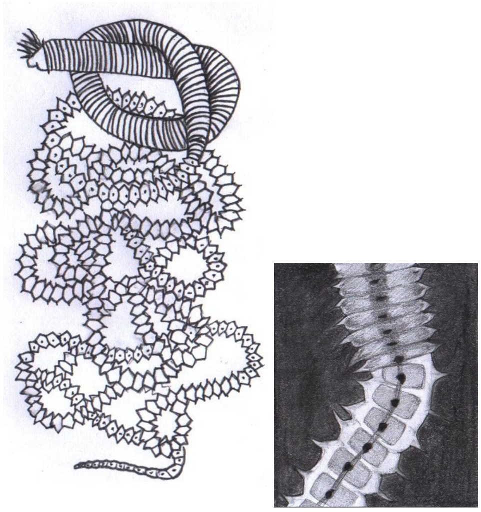

Figure 4.6: *Left: Palolo worm* Eunice viridis. *At the very top the 'atoke´ anterior, below the 'epitoke´ posterior part of the worm-like body. Right: Close up of the transition part between anterior (top) and posterior part (bottom). Sexual products (here: sperms) of the epitok are discharged and swim to the surface of the sea. There fertilization takes place. Ventral cord runs as dark band through midline of body; on top of it ventral eyes as dark spots; pointed appendices are gills. Drawn by Mareike Förster after Palmer (1974) (left) and Hauenschild et al. (1968) (right).*

200). Further indications are available (Dewan (1977), Dewan et al. (1978)). It is thus quite possible that a fixed phase relationship between moon cycle and menstruation cycle did exist in earlier times and that this feature was lost during 'civilisation'.

There are, however, some indications for a synchronized menstruation cycle between woman (Wilson (1992), Pfaff (1980), Jarett (1984), Trevathan et al. (1993)).[5] That was found also in a study performed at the Leibniz college in Tübingen (Germany) (Schweizer (1994)). Female students living together in pairs in a double room and spend much time together. 19 of the participants of the study had a regular cycle, in 12 participants the cycles fluctuated more strongly. In three of the 13 cases menstruation between the students of one room was in synchrony. There was also a tendency of a synchronized menstruation between several students ('phenomenon of the garbage containers filled with sanitary towels').

Equatorial monkeys of South America menstruate at the time of new moon, 14 days later at full moon ovulation and conception take place. Whether this implies a selective advantage or is a social effect is unknown.

[5] McClintock (1971) has interviewed (1) 33 pairs of female student roommates, (2) 33 pairs of close female friends in separate rooms, (3) 33 pairs of close female friends in the same rooms and (4) 33 random pairs of female students. The group (2) (33 pairs of close female friends in separate rooms) menstruated synchronously. Likewise Graham and McGrew (1980) found synchronous menstruation in 18 pairs being very close friends. Quadagno et al. (1981) transferred axillary pheromones to the upper lip. By this they were able to shorten the average time of menstruations to 9.3 days and after four months to 3.4 days. The experiments were repeated by Preti et al. (1986) using an alcohol control. The sensitivity toward the pheromones fluctuated with the menstruation cycle. Weller and Weller (1992) found in lesbian women living together permanently a high synchronization of menstruation. Synchronization of menstruation was observed also between mother and daughter in the same house (Weller and Weller (1993)). According to Dewan et al. (1978) the menstruation cycle can be regulated by light

5 Experiments

At the sea coasts there are surely a number of possibilities to observe lunar rhythms and to do experiments with the organisms. In the preceeding text of this book several hints are given. Here its is proposed how to check the monthly rhythm of the antlion (see also http://www.antlionpit.com/antlions.html with movie shots).

You find the animals in sand or in sandy soil at sunny, south facing locations, which are protected against too much rain and strong winds. Look during late spring and summer at escarpments, edges of the forests, or shrubbery. The pits are a reliable sign of antlion larvae living here. Watch the animals at their work. Throw sand in the pit and observe, how it is thrown out. If you put an ant at the rim of the pit, you can watch the catching.

For the experiment the best way is to dig out a larva together with the sand forming the pit and bring it in a container to your room. In a glass or plastic cuvette(at least 8 cm deep and 13 cm wide) you can take pictures of the hights of the pit. A digital camera is of advantage, because you can transfer the image to your PC and measure the hights. Level each day the pit with a rod. The antlion will immediately start to build a new pit. After completion you take another shot and wait to the next day in order to continue the play. Plot the hights of the rim of the pit in a diagram as a function of time (days) on millimeter paper or in a plot program. Mark the days with full moon. In an experiment you should place the cuvette at a window where the moonlight falls upon the container. In an other experiment make sure the moon light can not be seen by the animal. Feed the animal twice per day with an ant (more at http://www.antlionpit.com/antlions.html with movie shots).

6 Books and movies

Here are some of the most important books, articles and movies on rhythms related to the moon. Further literature can be found in the list of references.

Endres and Schad 1997: Biologie des Mondes. Mondperiodik and Lebensrhythmen. Hirzel, Leipzig. In this book - unfortunately in German only- numerous examples for tidal, forteen day and monthly rhythms are compiled and illustrated.

Palmer 1995: Biological clocks in marine organisms: The control of physiological and behavioral tidal rhythms. Wiley Interscience Publ. NY. Very stimulating book with informations concerning the underlying mechanisms of the described examples.

Articles on lunar rhythms appear regularly in various journals. Some of them are very competent, others superficial and sensational.

Neumann 1983: Die zeitliche Programmierung von Tieren auf periodische Umweltbedingungen, Rhein. Westf. Akad. Wiss. Vortr. N324, Seite 31-68

Movie on the grunion fish: Walker: Fish, moon and tides - the grunion story. Institut für den wissenschaftlichen Film, Göttingen, Ordering number W791

Neumann 1973: Semilunar reproduction of *Clunio marinus* - biological timing in the intertidal zone. Movie, Institut für den wissenschaftlichen Film, Göttingen, ordering number C1091 IWF Göttingen.

I have written a number of further books or am writing on them. They are also concerned with topics which have to do with rhythmic processes in organisms - my special field as a scientist (Engelmann (2007), Engelmann (2004c), Engelmann (2009a), Engelmann (2009b), Engelmann (2009b), Engelmann (2009c), Engelmann (2008), Engelmann (2004a), Engelmann (2004d), Engelmann (2004b)). There are further books; send a request for the pdf-files to engelmann@uni-tuebingen.de.

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