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60° tilt

The horns of the new moon—fishing for facts

by Nick Doe

23° tilt

In an article by Doris Lundy on archaeological motifs in British Columbia's rock art,[1] she remarked that, according to anthropologist Franz Boas, the Kwakwaka'wakw (Kwakiutl) [2] believed that if the new moon in March stood upright, that is, with the concave side toward the side [above *left*], then there would be few eulachon because the fish would be running out of the "moon canoe".[3] When, however, the new moon is seen with the convex side more downward [above *right*], there would be more fish because they couldn't run out.

She went on to add that among the Chumash of California, there was a similar belief concerning the crescent moon. They believed that if the "horns" were vertical, that is, one above the other [the tilt was high], then the moon was empty of rain. If they were horizontal, that is both pointing up [the tilt was low], then there would be plenty of rain for the coming year.[4]

All of which raises the questions, do the horns of the new moon in spring vary their orientation from year to year? if so why? and what could this possibly have to do with eulachon runs? Here's what I discovered when I looked into this.

I should add at this point, I had little confidence that a connection would be found. The strength of euachon runs varies from year-to-year for multiple, only poorly understood, reasons. But…you never know.

The basic astronomy

The earth rotates on its axis counter-clockwise once every 23 hours and 56 minutes. As a result of this rotation, if we look south, the sun, moon, and stars appear to be continuously crossing the sky from east to west (left to right); however, because the earth is moving around the sun, the sun does not appear in the same position relative to the stars on completion of each rotation. We have to wait an additional four minutes for the earth's rotation to catch up with the sun and for the sun to appear at the same azimuth (bearing) it had the previous day.[5]

[1] Doris Lundy, *Places of power—speculations on archaeological motifs in British Columbia rock art*, *SHALE* 26, pp.19–30, November 2011.

[2] The traditional (pre-contact) territory of the Kwakwaka'wakw stretches from Johnstone Strait into Queen Charlotte Sound and the central coast of BC. Boas did most of his studying at the Hudson's Bay Company post at Fort Rupert near present-day Port Hardy at the north end of Vancouver Island.

[3] *Thaleichthys pacificus*, a smelt found along the Pacific coast of North America from northern California to Alaska. They spend most of their adult lives in the ocean but return to their natal freshwater streams and rivers to spawn and die.

[4] Some folklore has it the other way round—"tipped moon wet, cupped moon dry". A friend of mine's Irish grandfather used to say that the moon had to be *really* tipped and *really* horizontal for this to be true.

[5] The usual "azimuth" is due south or 180°. Another way of looking at the rotation is to see the stars as

The (average) interval between the sun being at the same observed azimuth it was the previous day is thus 24 hours, which is, of course, how we define a day.

The path that the sun takes relative to the background of stars is called the ecliptic, and the sun moves around the ecliptic counter-clockwise once a year at an average rate of 0.986° each day.[6] To an observer looking south,[7] the ecliptic is an imaginary arc that rises above the horizon from the east, reaches its highest point due south, and sinks back to the horizon toward the west. The sun's movement along this arc, discounting its daily rotation, is west to east.

The height of the ecliptic at mid-day appears to an observer to vary throughout the year, as do the azimuths of sunrise and sunset, but this is not because the ecliptic moves; it is because the sun occupies different parts of it throughout the year. The high point of the ecliptic occupied by the sun in summer, also appears in the same position in winter, but it does so in the middle of the night instead of at noon (6 months of delays at 4 minutes a day equals a 12-hour delay).[8]

The path of the moon is similar to that of the sun, but it rotates faster than the sun. It moves counter-clockwise, on average, 13.18° relative to the stars each day completing an orbit in 27.32 days.[9] Because during this time the sun has moved on in the same direction, west to east, about 27°, the moon needs a couple of days to catch up, making the average interval between one new moon and the next about 29.53 days.

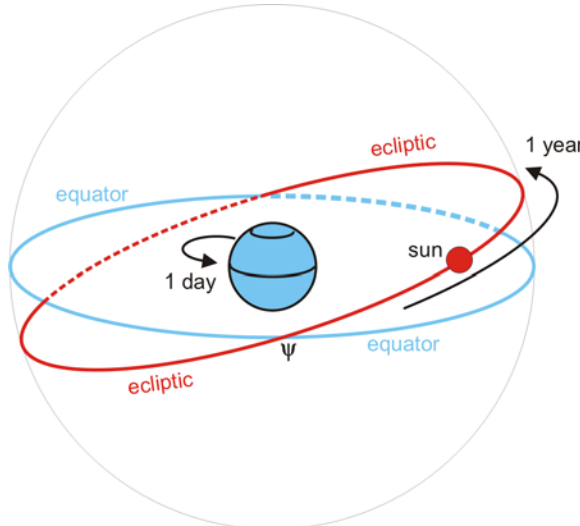

Figure 1: The celestial sphere with the rotating earth at the centre. The sun moves along the ecliptic completing one circuit every year. ψ is the first point of Aries, the position of the sun at the spring equinox.

There are on average 12.36875… lunations (monthly cycles) each year. Because this number is not an integer, it is impossible to come up with a calendar that connects phases of the moon with seasons of the sun. Each year is different, and no year's tide tables are exactly the same as those of a previous year.[10]

moving closer to the setting sun every day. There is evidence on Gabriola that Orion may have been viewed this way by whoever carved some of the petroglyphs. Orion, perhaps depicted as a dragon-like creature, pursues and finally catches up with the setting sun and brings winter to an end in April. It won't be seen again until October. Dragons with fiery (warm) breath were symbols of "life" in many cultures.

[6] It varies between 0.983° at aphelion and 1.016° at perihelion. The earth's orbit is slightly elliptical.

[7] Apologies to those living south of the equator.

[8] Part of the interest of prehistoric peoples in the Pleiades star cluster (the Seven Sisters) is that they lie, give or take a degree or so, on the ecliptic, but, except on time-scales of thousands of years, they, unlike the sun, don't move along it.

[9] It varies between 11.8° at apogee and 15.4° at perigee. The orbit is only approximately circular.

[10] One attempt at a calendar equates 235 lunations to 19 years. It was used by the Babylonians and the Chinese and survives in the modern Jewish calendar. The moon at the end of the 19th year is about 2 hours late—close, but not close enought for tide tables.

The seasons

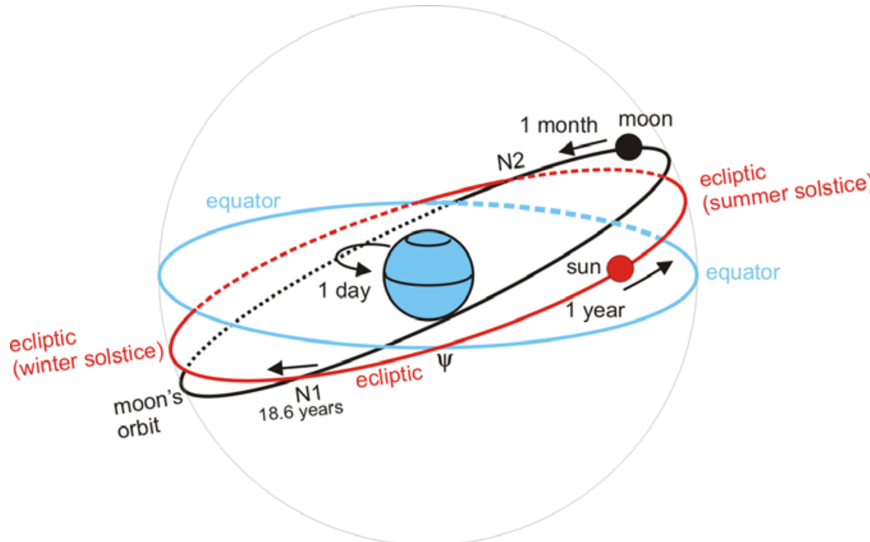

Figure 2: The celestial sphere. The moon moves along an orbit slightly inclined to the ecliptic. N1 is the position on the ecliptic of the ascending node of the moon's orbit, shown here fairly close to ψ, the first point of Aries, the position of the sun at the spring equinox. In this configuration, the moon at its height in its monthly orbit is higher in the sky than is the sun at the summer solstice. The line of nodes in the plane of the ecliptic, N1–through the centre of the earth–N2, rotates clockwise once every 18.6 years, so in the configuration where N1 is about where N2 is in the diagram, the moon at its height in its monthly orbit is lower in the sky than is the sun at the summer solstice.

That we have seasons at all is because the ecliptic is inclined to the plane of the earth's equator [Figure 1]. At midsummer, the sun is on that part of the ecliptic that is 23.4° above the earth's equatorial plane; so the sun appears 23.4° higher in the sky at noon than the annual average. At midwinter, the sun is on that part of the ecliptic that is 23.4° below the earth's equatorial plane; so the sun appears 23.4° lower in the sky at noon than the annual average.

The exact height of the sun at noon depends only on your latitude; the higher the latitude (the further north you are) the lower in the sky it appears.

At latitude 49° N for example, which happens to be where I live, the sun at noon on the day of the summer solstice in June is (90 – 49) + 23.4 = 64.4° above the horizon. At noon on the day of the winter solstice in December, the sun is only (90 – 49) – 23.4 = 17.6° above the horizon.

Only at the equinoxes is the sun briefly on the earth's equatorial plane as it crosses from being below the plane to above it in spring, and vice versa in the fall. The position of the equinoxes as seen against the background of stars changes only very slowly.[11] The position in the sky of the ascending node of the sun at the spring (vernal) equinox is still known to astronomers as the first point of Aries (ψ), though in the last two thousand years it has moved into the constellation of Pisces.

The moon's orbit

Although we tend to think of the moon most often as orbiting the earth, in fact, its principal motion is around the sun. If one were to trace the path of the moon in space, it would appear as a near-perfect circle around the sun with only the slightest wobble to indicate that it was also weaving its way back and forth around the earth.

[11] The change is due to the tidal forces of the sun and moon on its equatorial bulge. A complete precessional cycle of the line joining the equinoxes (the equinoctial line) takes 26,000 years.

The plane of the moon's orbit is inclined 5.1° to the ecliptic. Because this inclination is small, the moon in its monthly orbit is never very far from the annual path of the sun across the observer's sky. The moon would frequently pass in front of the sun (a solar eclipse), or pass through the earth's shadow (a lunar eclipse) if it weren't for the fact that the solar and lunar discs are quite small, despite their being so conspicuous.

The direction of the inclination of the moon's orbit relative to the ecliptic is not fixed, but rotates around the ecliptic once every 18.6 years [Figure 2]. The changes in the movement of the moon in the sky brought about by this rotation are quite noticable and there is no doubt that some prehistoric people were aware of it.[12]

When the moon is in that part of its 18.6-year cycle that the inclination of its orbit is in the same direction as the inclination of the ecliptic, the moon in its monthly cycle alternates between being 23.4 + 5.1 = 28.5° higher and 28.5° lower in the sky than average.[13] When the moon is in that part of its 18.6-year cycle that the inclination of its orbit is in the opposite direction to the inclination of the ecliptic, the moon in its monthly cycle alternates between being only 23.4 – 5.1 = 18.3° higher and 18.3° lower in the sky than average.[14]

To translate these numbers to what an observer sees, in a year when the obliquity of the moon's orbit is greatest, at latitude 49° N, a full moon in winter[15] will reach (90 – 49) + 23.4 + 5.1 = 69.5° above the horizon due south. This is often startlingly high, easily giving the impression that it is almost directly overhead. A full moon in summer at this time will appear (90 – 49) – 23.4 – 5.1 = 12.5° above the horizon due south. The moon always appears to be hanging very low on the horizon.

Conversely, when the obliquity of the moon's orbit is least, at a latitude of 49° N, a full moon in winter will only reach (90 – 49) + 23.4 – 5.1 = 59.3° above the horizon due south, which is less than the height of the mid-day sun in summer and not particularly impressive. A full moon in summer at this time will reach (90 – 49) – 23.4 + 5.1 = 22.7° above the horizon due south, which is low, but not as low as the mid-day sun in winter.

What we are ultimately going to be interested in is how these changes in the position of the moon affect the tides in the river estuaries and hence, just maybe, the eulachon runs.

New moon

At new moon, which is technically when the eclipic longitude (λ) and right ascension (celestial longitude) (α) of the sun and moon are the same (conjunction), the moon can never be more than ±5.1° from the sun in ecliptic latitude (β).

[12] If the moon's orbital plane didn't rotate, solar eclipses would occur at fixed times of the year. As it is, solar eclipses, when they occur, do so roughly five or six days earlier for each half-year since the last one.

[13] The variation in declination is highest. Declination (δ) and right ascension (α) are the celestial equivalents of latitude and longitude. When the declination is the same as your latitude, the celestial object will pass directly above your head.

[14] The current cycle is 1997 (ascending node at fall equinox—declination limits minimum), 2002 (ascending node at summer solstice—declination limits average); 2006 (ascending node at spring equinox—declination limits maximium), 2011 (ascending node at winter solstice—declination limits average), 2016 (ascending node at fall equinox—declination limits minimum).

[15] Also a new moon in summer, though it will not be visible in daylight when it is due south.

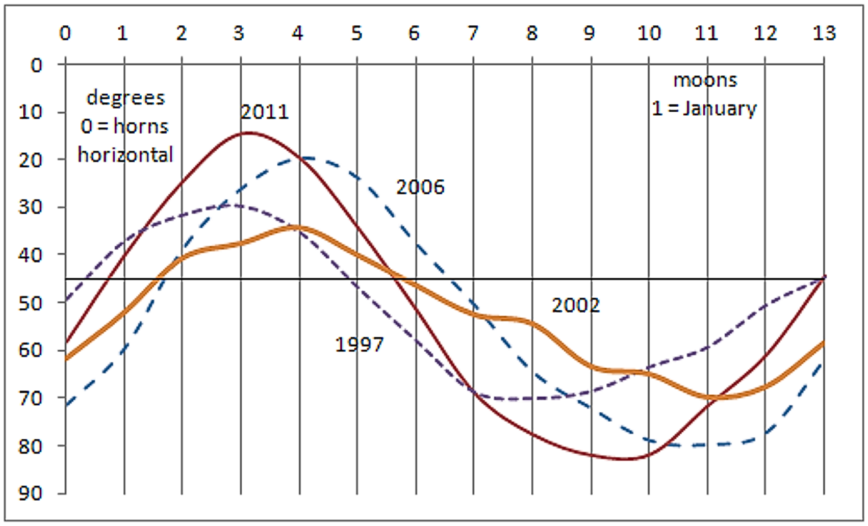

Figure 3: The orientation of the horns of the new moon when it first becomes easily visible at sunset. The horizontal scale is a count of the new moons in a year with 1 being the new moon in January. The vertical scale is the angle of tilt of the horns with 0° at the top corresponding to horizontal. Four years are shown corresponding to four directions of the tilt of the moon's orbital plane relative to the ecliptic: 1997 N1 at fall equinox (orbit inclined toward winter solstice); 2002 N1 at summer solstice (orbit inclined toward fall equinox); 2006 N1 at ψ (orbit inclined toward summer solstice); and 2011 N1 at winter solstice (orbit inclined toward spring equinox). Latitude 49° N.

Differences in the phases of the cycles are likely not important and arise because the timing of a new moon with respect to the spring equinox varies by up to ± half a month from year-to-year. There is also variation because, at the moment of conjunction, the moon may be positioned close to or far away from the observer's longitude. The position of the moon moves so fast relative to the sun and stars that it was used by late-18th century navigators as a celestial clock from which they could determine GMT and hence their terrestrial longitude.

We can never see the moon at conjunction for two reasons. One is that the illuminated half of the moon is facing almost directly away from the earth and any crescent is too thin to be visible; and the other is that the glare of the sun is too great. Even if you know where to look, and even if you use optical aids, the moon has to be at least 11° away from the sun before its crescent becomes visible. We therefore only see the "new" moon some time after conjunction.

In order to be more precise, I consulted a few Islamic sources—not the first time a European has had to do that where cosmology is concerned. One site showed a lunar calendar constructed according to the rules of the Fiqh and Islamic Councils of North America (FCNA & ICNA),[16] and its maps showed four categories of new moon sightings, namely:

—visible with optical aid only;
—needing an optical aid to locate the moon;
—visible under perfect conditions; and
—easily visible with the naked eye.

According to my calculations for Vancouver Island, the average distance between the sun and moon when the new moon was first "easily visible with the naked eye" was 22°, or effectively, two days after conjunction.

The geometry of the horns

One of the (to me) startling suggestions reported by Doris Lundy in her article[17] was that "…the horns of the moon are always

[16] Some Muslims take the start of a new month to be when the new moon is actually seen with the naked eye. Since this moment is not precisely predictable, and depends on your location, it is impossible for them to construct a calendar for future dates. This simple fact has created an amazing amount of controversy in the Islamic world over the centuries, and the controversy is not over yet.

[17] Doris Lundy, *ibid*, p.28.

horizontal in the spring…". The implication of this is that you can tell whether it's spring or fall just by looking at the tilt of the horns of a new moon, a connection between the orbits of the moon and sun that I'd always thought of as being unconnected.

Nevertheless, it is perfectly true; the horns do always tend to be more horizontal during the first half of the year than the second. The reason briefly is that during the two-day wait for the moon to become visible after conjunction, the moon has moved on in its orbit, which because this roughly follows the ecliptic, means that the moon tends to move toward a position that the more-slowly-moving sun will be reaching only about 27 days later.

During the spring, the sun is moving higher in the sky day-by-day and the azimuth of sunset is moving north. Hence, at sunset, the position of the sun as it will be 27 days in the future will be higher than, and heading beyond, its present position. The moon, once it becomes visible, tends therefore to be illuminated more on its underside and the horns correspondingly appear more nearly horizontal, though at my latitude still tilted.[18]

Conversely in the fall, the sun is generally moving lower in the sky day-by-day, and the azimuth of sunset is moving south. Hence, at sunset, the position of the sun as it will be 27 days in the future will be lower than, and short of, its present position. The moon, once it becomes visible, tends therefore to be illuminated on its side and the horns appear more nearly vertical, though again at my latitude still tilted.

[18] A new (waxing) moon is always illuminated on its right side; a crescent seen just before sunrise with its illuminated side on the left is the end of an old (waning) moon.

The seasonal variation

The fact that the horns of the new moon tend to be more horizontal in the spring than in the fall [Figure 3] can be used as an explanation for the observation that the geometry of the horns is related to the timing of the wet season. It is easy to understand that in some societies (not excluding our own) there might be a belief that the geometry *causes* the rain or lack thereof.

In the more northern latitudes along the west coast of North America (and Ireland), the climate is Mediterranean—cool wet winters, warm dry summers. Near horizontal horns in spring would then mean drying weather.

In more southern latitudes, and away from the coast, the climate tends to be a savanna climate—wet summers, dry winters. Near horizontal horns, meaning spring, would then presage wet weather, as I suppose was true for the Chumas of California where and when their observation was made.

The reported observation of the Kwakwaka'wakw connecting the orientation of the horns with the eulachon runs however might be rather more subtle than an observation that eulachon runs occur in the spring. That much would have been obvious to everyone. So the question is, does the fact that the moon doesn't exactly follow the ecliptic make a difference to the tides and hence possibily either the size of the runs or the ease with which the fish could be caught? And to answer that, we need to do some algebra.

The cycle of the moon's orbital plane in March

Let's first focus our attention on the movement of the moon relative to the sun at the spring equinox in March under two circumstances.

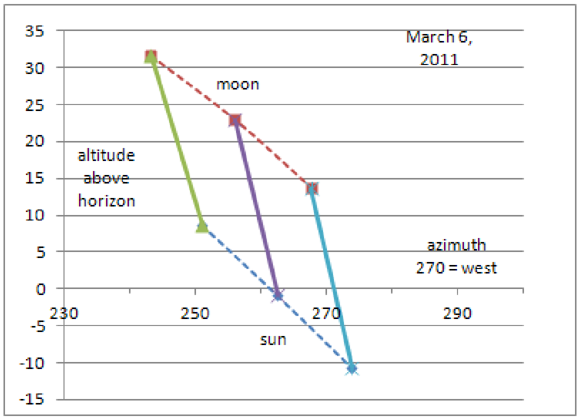

Figure 4: The azimuth and altitude of sun and moon shown one hour before sunset, at sunset, and one hour after sunset.

The solid lines join the positions of the moon and sun at these various times. The dotted lines show the paths of the setting moon and sun. The more nearly vertical the solid lines, the more horizontal are the moon's horns; the tilts are 16.6°, 14.5°, and 14.4°.

The day is the first day the new moon closest to the spring equinox becomes easily visible with the naked eye. The year is one when the moon's orbit is tilted toward the position of the spring equinox. The calculations are for 49°N, 123°W.

One is where <u>the direction of the inclination of the moon's orbit is in the direction of the first point of Aries</u>.[19] The moon at conjunction around the time of the equinox will be passing above the sun and hence, one would think, would most likely to have near horizontal horns once visible. It was approximately so in <u>2011</u> [Figure 4].

The second is where <u>the direction of the inclination of the moon's orbit is directly away from the direction of the first point of Aries</u>.[20] The moon at conjunction will be

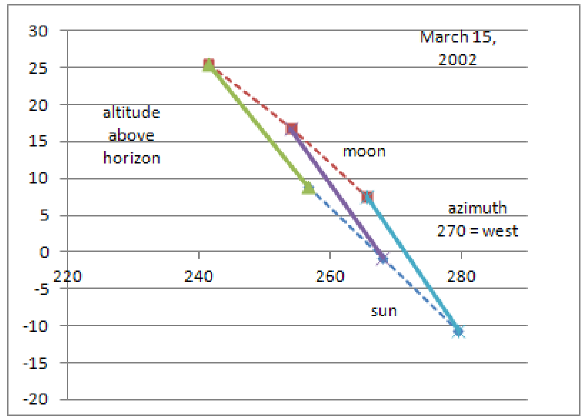

Figure 5: As for Figure 4 except that the year is one when the moon's orbit is inclined away from the position of the spring equinox. The tilts of the horns are 39.2°, 37.6°, and 38.0°.

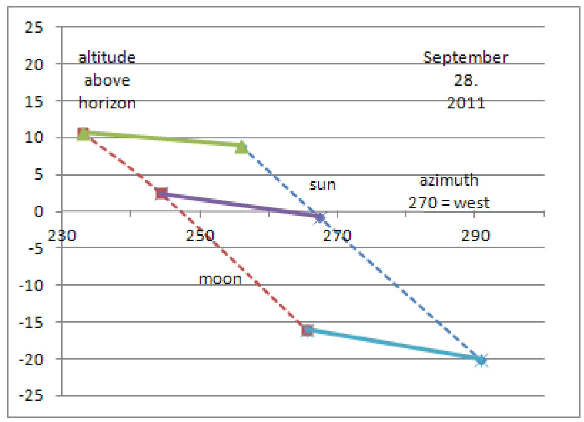

Figure 6: As for Figure 4 but in the fall of 2011. The verticality of the horns would have been particularly evident as the moon set to the south of the sun just after sunset. The tilts are 83.7°, 81.9°, and 84.4°.

passing below the sun although too close for us to be able to see it. In the spring, in the time it takes for the moon to move away from the sun far enough for us to be able to see it, it will always have moved into a position above the sun, but this is the time one would most likely see the moon lit from

[19] A "not bad" year for this ideal configuration would be 1974 when the ecliptic longitude of the moon at the spring equinox was –96.2° and there was a new moon on March 23 when its declination locally was +6.7° at sunset.

[20] In 1983, the ecliptic longitude of the moon at the spring equinox was a near-perfect 89.7°. The new moon however was a bit early on March 14, but its declination locally was –5.4° at sunset.

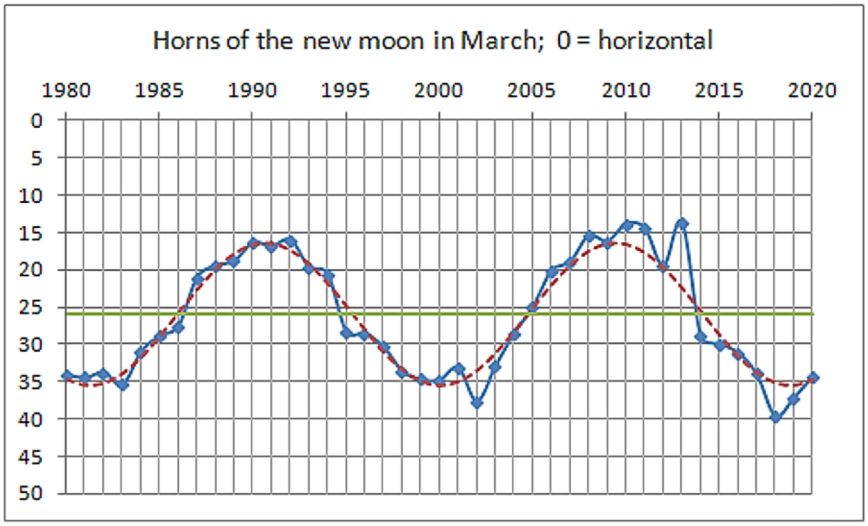

Figure 7: The orientation of the horns of the new moon when it first becomes easily visible at sunset close to the spring equinox. The horizontal scale is calendar years. The vertical scale is the angle of tilt of the horns with 0° at the top corresponding to horizontal. The tilt indicated by the dotted trend line is 26.0 ± 9.6°.

Although the tilt oscillates through the 18.6-year cycle of the plane of the moon's orbit, the horns in March are always more horizontal (tilt less than 45°) than vertical. Latitude 49°N.

the side. It was approximately so in 2002 [Figure 5].

Although it is natural to be thinking about the orientation of the horns in spring when the eulachon run, similar but opposite effects occur in the fall [Figure 6]. Perhaps a particularly canny observer, seeing that the horns were vertical around the fall (autumnal) equinox, might keep this fact to himself or herself until the spring, and then announce to all, shortly *before* the new moon, that the horns would that year be nearly horizontal! Amazingly, he (or she) would be right.

What else is new?

Figure 3 shows the orientation of the horns of the moon throughout the year[21] for four different years:

- 2011 when the moon's orbit is inclined toward the ecliptic at the spring equinox and the ascending node N1 is at the sun's position at the winter solstice;
- 2002 when the moon's orbit is inclined away from the ecliptic at the spring equinox and the ascending node N1 is at the sun's position at the summer solstice;

plus two in-between years;

- 2006 when the ascending node N1 is at the sun's position at the spring equinox—the moon's declination will be the same as the sun's but rising fast; and
- 1997 when the descending node N2 is at the sun's position at the spring equinox—the moon's declination will also be the same as the sun's but decreasing rapidly.

You can see from the graphs that the orientation of the horns is always less than 45° (more horizontal than vertical) between the 2nd and 5th new moons (February and May) at latitude 49° N. The horns are more horizontal than vertical in March every year [Figure 7].[22]

[21] The horizontal scale is lunar months with 1 being the new moon in January. The numbers almost correspond to calendar months, but the match is not exact because a lunar (synodic) month has 29.53 days, but the Gregorian calendar we use has months with an average of 365.2425/12 = 30.44 days.

[22] Figures 7 and 8 are calculated for latitude 49° N. For other latitudes on the coast, an adequate

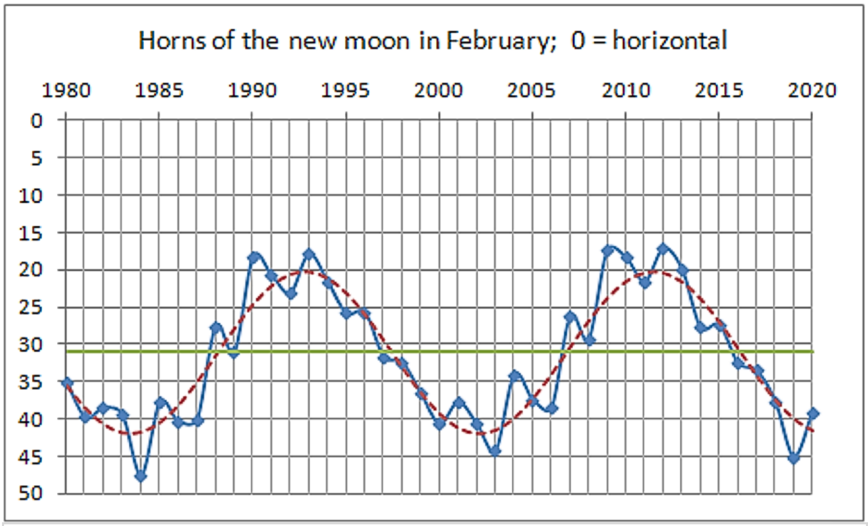

Figure 8: The orientation of the horns of the new moon in February. The horizontal scale is calendar years. The vertical scale is the angle of tilt of the horns with 0° at the top corresponding to horizontal. The tilt indicated by the dotted trend line is 31.1 ± 10.9°. Latitude 49°N.

The tilt oscillates through the moon's 18.6 year cycle, mostly horizontal and only rarely being vertical (greater than 45°). The small 3-year perturbation cycle is the result of year-to-year variations of the date of the new moon in February. These variations look repetitive because there are close to 37 complete lunations every 3 years.

So does the folklore of the Kwakwaka'wakw amount to nothing more than a statement that the eulachon run in March and the horns of the new moon at that time are always more horizontal than vertical? It is admittedly an astute observation—in sixty or more years of new moons, I'd never noticed that—but as a way of predicting the size of the eulachon run, it probably is not the best tool there is. So let's look for an "unless…" including the possibility that the prediction has become garbled over time.

March?

There are several ways of digging into this a bit deeper, but let's start with the phrase "…if the new moon in March stood upright…". Since this is meant to be a prediction, the implication is that the eulachon usually run in late-March at the earliest, and possibly in April. Is this true?

According to Fisheries and Oceans Canada (DFO), "spawning begins in early March in most British Columbia rivers such as the Skeena and Nass [on the northern BC coast], but it begins later in April and May in the Fraser".

More detail is provided by Megan Moody who cites runs on the central BC as generally being mid- to late-March, but in April in Johnstone Strait in the heart of Kwakwaka'wakw territory.[23] As Megan's careful research points out however, we have to take into account that during the last century, eulachon runs have been occurring earlier than they used to because of global waming. The average advance throughout the 20th century of the peak of the Bella Coola run has been 0.34 days/year,[24] which is quite sufficient to push back modern-day runs in early-March to April or even early-May in pre-contact times.

So it looks like a new moon in March was a good time to be making predictions except

approximation is to simply add (subtract) 1° of tilt for every 1° increase (decrease) in latitude.

[23] Megan Moody, *Eulachon past and present*, M.Sc. thesis UBC, March 2008. Douglas Channel p.33; Gardner Canal p.36; Johnstone Strait p.41. In California, runs have been observed starting as early as December, although only reaching a peak during March and April p.56.

[24] Moody, *ibid*, p.201.

for one thing. The weather in March can be bad. Megan reports in her thesis that a Nuxalk Elder described the weather during the eulachon season when he was a kid as being "fierce".[25] "There'd be wind blowing, rain, hail and snow, all together, 'eulachon time', that's what they were waiting for."

If I were in the forecasting business, I'd be looking at February for two reasons. One as a backup just in case the new moon was nowhere to be seen in March; and two because, as shown in Figure 3, the horns would be less predictably horizontal in February.

Figure 8 however shows that the February orientation of the horns of the new moon doesn't differ substantially from the orientation in March. They are tilted about 31.1–26.0 = 5.1° more when averaged over an 18.6- year cycle, but the variation from maximum to minimum, a tilt of ±10.9°, is practically the same as the ±9.6° variation in March. Disappointing, but there you are.

Weather

Most meteorologists accept that numerous scientific studies have failed to establish any connection between the moon and the weather.[26] If a connection does exist, it must be very weak and very easily masked by local conditions.[27]

Tides

It is unlikely that eulachon are astronomers, but they do care about tides especially when they are running up rivers, and it's the movement of the moon and sun that creates tides. The question is, are the variations in the moon's orbit that create differences in the springtime orientation of the horns sufficient to affect tides in a way that matters either to the eulachon, or to the people fishing for eulachon? I don't think so…but let's see.

Basic tidal theory

The four groups of factors that determine the tides are:

- astronomical factors—the ever-changing positions and distances of the sun and moon;
- geomorphological factors—the size, shape, and depth of ocean basins; and the form of the coast, particularly its bays, fjords, narrows, and inlets;
- in rivers, the volume and speed of their flow, and funnelling by the banks and river bottoms as one moves upstream; and
- the weather. Prolonged strong onshore winds and low barometric pressure can easily raise high tide levels by more than a foot above predicted levels.

[25] Moody, *ibid*, p.200.

[26] Although not relevant to the present study, there have been a few claims in peer-reviewed scientific literature that weather is linked to phases of the moon. See for example, R.S. Cerveny, B.M. Svoma, and R.S. Vose, *Lunar tidal influence on inland river streamflow across the conterminous United States*, Geophysical Research. Letters, 37, L22406, doi:10.1029/2010GL045564, Nov. 2010.

[27] The Internet has many pseudo-scientific sites that declare as established facts apophenic connections between the moon and the weather, even though, in almost all cases, investigations have provided no scientific evidence that the assertions are true. Most folklore is based on selective memories, anecdotes, faulty statistics, and "what grandmother used to say"and makes use of the appearance of the moon, as opposed to the moon itself, to judge current high-altitude atmospheric conditions. New moons are often impressive, especially to the casual observer who habitually looks for the waxing moon at dusk, but less diligently watches for the waning moon at dawn. It's easy to imagine that such an observer might associate fine dry weather with the new moon for the simple reason that when the weather is wet and cloudy, the new moon would neither be seen, nor, without checking a calendar, expected.

Weather and tides

The influence of the weather we've already discounted. That there is such an influence is not a surprise to people who spend time messing about in small boats; or have waterfront property being eroded by winter storms when barametric pressure is low; or who, along with their children and grandchildren, marvel at the lowness of the tide and the abundance of tidepools when barometric pressure is high on fine-weather days in summer.

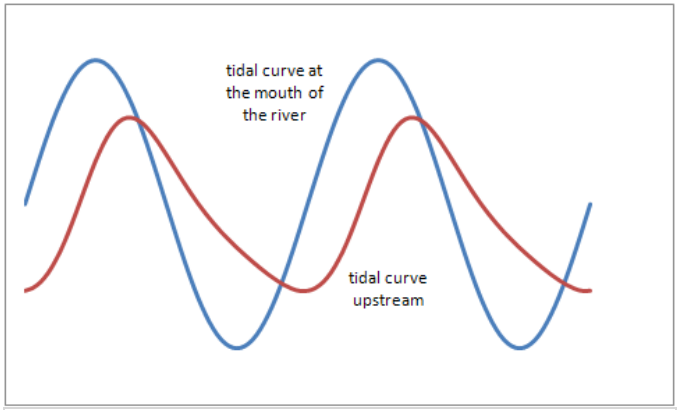

Figure 9: Compared to the tide at the mouth of a river (blue), the tide some way upstream (red) is delayed, is smaller, and typically floods faster and ebbs more slowly. Waves on the beach behave similarly for the same reasons.

Rivers and tides

Tides in tidal rivers are potentially interesting to both eulachons and the people who fish for them using traditional methods.

As a rising tide progresses up a river, the water flowing from the sea loses momentum (it slows) as it climbs uphill. The initial flow of the flooding tide may also be slowed by the counter-flow of the river, and by turbulance in shallow water over a rocky river bed.

The deeper water from the sea further behind however moves faster—it has less of a height difference to overcome (the water in the open ocean has in the meantime risen), and as the river deepens, the bulk of the flow becomes less disturbed by the presence of the river bed.

The result is that, although the rising tide is delayed upstream, when the water does eventually get there it begins to rise rapidly because it is a combination of slow-moving water that left the ocean relatively early, and fast-moving water that left relatively late.[28]

The reverse happens on a falling tide. Although the water upstream may flow rapidly seaward, in shallower parts of the river the volume of this moving water is low compared with that downstream and so the fall is both delayed and prolonged.

In short, as shown in Figure 9, compared to the tide at the river mouth, the rate of rise of the tide upstream is higher, but the duration of the rise is briefer; and the rate of fall upstream is less, and the duration of the fall is longer.

It's easy to imagine that the more rapid rise of a flooding tide progressing up the river assists the euchon struggling to reach their spawning grounds, and that the more languid and prolonged fall of an ebbing tide assists those fishing for exhausted euchon drifting back downstream.[29]

The question is, is the rate of rise of the tide influenced by the position of the moon's

[28] In extreme cases, all the water may appear at some point upstream at the same time and the rising tide then appears as a bore. For individual waves on a beach, the later water often overtakes the earlier water and the wave breaks creating surf.

[29] Hilary Stewart, *Indian fishing—early methods on the Northwest Coast*, pp.95–97, University of Washington Press, 1977. I don't know if the suppositions in this paragraph are true or not.

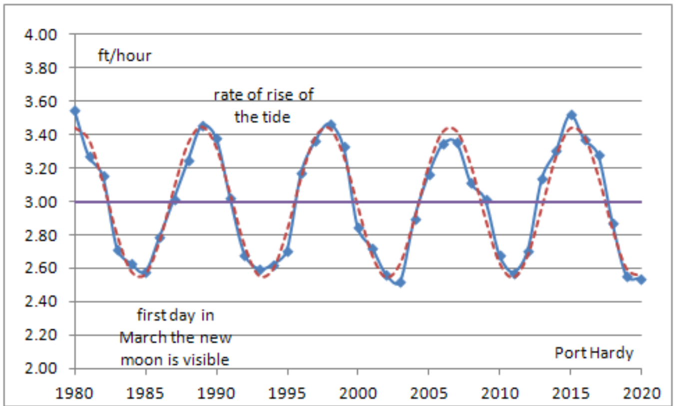

Figure 10: The rate of rise of the daytime tide at Port Hardy does vary from year to year at the new moon in March, although, as expected, it does not show any sign of the asymmetry it would in shallow water. The cycle has a period of 8.8 years, and so has nothing to do with the 18.6-year cycle of the position of the nodes of the moon's orbit and the tilt of the horns. The rate of rise is highest when the moon is closest to the earth (perigee). This is when the gravitational pull of the moon is highest, and because of the moon's greater velocity, the length of the lunar day is longest and tidal forces are prolonged.

orbit in its 18.6-year cycle? And the answer is yes, but the effect is very small, so small that it is essentially theoretical rather than real. A far stronger influence is the position of the moon in its elliptical orbit at the vernal equinox—its proximity to perigee—and this position goes through an 8.85-year cycle. Although the position affects the apparent size[30] and brightness of the moon, it has no influence on the tilt of the new moon's horns.[31]

[30] Roughly between 0.49° and 0.55°.

[31] Well, very little. In Figure 3, you can see that the tilt of the moon's horns is low (14.5°) in 2011. On March 6, 2011, the ascending node was at λ=269°, so the inclination of the orbit was toward ψ. On March 13, 1918, the ascending node was at λ=267°, so the inclination of the orbit was also toward ψ, and the tilt was also relatively low (20.4°). Yet, in 2011 the moon was only 2° from apogee, and in 1918 only 5° from perigee. So the influence of the ellipticity of the moon's orbits on the tilt of the moon's horns is small.

Geomorphology and tides

There are many ways that the tides move up and down inlets, around islands, and through narrow passages on British Columbia's intricate 27-thousand kilometre coast, but except for some weak non-linear frequency components over shoals,[32] there is no frequency component in the tides that isn't present in the tides of the open Pacific. The shape of the shore may diminish, amplify, and change the timing of components, but it doesn't create new ones in other than very shallow water, so for present purposes we can side-step the details and just look to the tides on the outer coast.

Astronomical factors and tides

The Pacific is wider and deeper than the Atlantic and this allows for the transmission of more lower-frequency components. These components arise because the sun's and moon's orbits are only approximately circular. The moon's orbit in particular is not even of a constant shape; it continually changes in response to the ever-changing direction and strength of the earth and sun's gravitational pull' and with these changes comes changes in the moon's orbital velocity.[33]

The modern method of forecasting tides[34] looks at the tidal records of the past and projects them into the future. The simplest way to do this mathematically is to model the tide as a continuous sinewave. To cater for all the complexities of the sun and

[32] Shallow-water components are simple multiples (harmonics) of the main frequency components and sums and differences of these. None are completely unrelated to the main deep-water components.

[33] The principal perturbations are called lunar evection and lunar variation.

[34] Gabriel Godin, *The Analysis of Tides*, University of Toronto Press, 1972.

moon's movements, many more than a single sinewave is needed; however, since the projection is simple for one frequency component, it is simple for all frequency components. Each component is projected as a stand-alone tide, and when this is done, all the components are added together to get the composite forecast. Each component has its own fixed frequency, fixed amplitude, and fixed phase,[35] and these vary from location to location, but the general procedure for the calculation is always the same.

Rather than plough through volumes of old tide tables to discover the effect of changes in the moon's orbit on tides along the outer coast, I used a tide predicting program (a frequency-domain only version) based on the work of Foreman, Godin, and Doodson, to calculate the height of an artificial tide. The date was set at March 21 (spring equinox), and the longitudes of the sun and moon were set to zero (Doodson's j_0 and k_0). The variables were for rotation of the nodes (Doodson's $-m_0$) and for rotation of the perigee (Doodson's l_0). All other terms were arbitrarily left for the year 1964 and were not expected to significantly change the results. The station was Tofino.

The results were as follows:

	asc. node	height ft.	time PST
perigee	mar.	12.0	0645
perigee	jun.	11.9	0652
perigee	sept.	12.1	0642
perigee	dec.	12.2	0634
		12.0	0643
apogee	mar.	10.9	0705
apogee	jun.	10.8	0712
apogee	sept.	10.9	0702
apogee	dec.	11.0	0655
		10.9	0704
perigee	mar.	2.5	1252
perigee	jun.	2.8	1253
perigee	sept.	2.3	1250
perigee	dec.	2.0	1247
		2.4	1251
apogee	mar.	3.5	1314
apogee	jun.	3.7	1317
apogee	sept.	3.4	1313
apogee	dec.	3.2	1310
		3.4	1314
perigee	mar.	12.0	1900
perigee	jun.	12.3	1901
perigee	sept.	12.1	1859
perigee	dec.	11.9	1859
		12.1	1900
apogee	mar.	10.8	1921
apogee	jun.	11.0	1923
apogee	sept.	10.9	1922
apogee	dec.	10.7	1922
		10.9	1922

The mean difference in the height of the morning high water when the moon is at perigee and when it is at apogee is 13.7 in.(0.35 m) yet the variation in the

[35] Readers familiar with tidal analysis will know that in the past, when computers were far less powerful than they are today, it was customary to regard only the "main components" of the tide as having fixed properties. These main components were then modulated in time to account for the smaller "satellite components". The method was thus a mix of frequency- and time-domain analysis. Nowadays, that isn't necessary and no distinction need be made between a main component and the sidebands resulting from the modulation—everything can be done in the frequency domain, even though some of the resulting computation may be superfluous and the precision required is high. The program used by the Canadian Hydrographic Service (M.G.G. Foreman, *Manual for Tidal Heights Analysis and Prediction*, Pacific Marine Science Report 77-10) identifies 69 main components plus 77 possible shallow-water components, a total of 146. When all the sideband components are included (Godin) and modulation dispensed with, the total number rises to about 309.

height of the same tide over an 18.6-year cycle at perigee and apogee is only 1.3 in. (0.03 m).

Similarly, the mean difference in the height of the noon low water when the moon is at perigee and at apogee is –12.4 in.(–0.31 m) yet the variation in the height of the same tide over an 18.6-year cycle at perigee and apogee is only 3.1 in. (0.08 m).

Proof enough that it's virtually impossible that the tilt of the horns can tell you anything about the observable tides. The same message is apparent in sample tide charts.

Figures 9A–D show the tides at Port Hardy in March for four stages of the 18.6-year cycle. Note for example that for the two charts on the right, Figure 9B (2002, asc. node $\psi + 90°$, perigee $\psi + 180°$) and Figure 9D (2011, asc. node $\psi - 90°$, perigee $\psi + 180°$), show higher spring tides at full moon than at the previous new moon while the two charts on the left, Figure 9A (1997, asc. node $\psi + 180°$, perigee ψ) and Figure 9C (2006, asc. node ψ, perigee ψ), show lower spring tides at full moon than at the previous new moon. If the position in the 18.6-year cycle made a difference, the two upper charts would differ from the two lower charts, but they don't. The difference is between the two charts on the left and the two on the right, which is due to the 8.8-year cycle of the perigee which happens to be close to half the period of the rotation of the ascending node.

Conclusion

The myth that the tilt of the horns of the new moon in March is an indication of the strength of the coming eucholon run is, in the word of the popular TV series, busted. There is no connection that I can see.

However, it is true that the horns of the crecent moon are less tilted in March than at other times of the years. And it's easy to see from this how the myth might have arisen.

February must have been a bleak month in the calender of the Kwakwaka'wakw. The weather was bad; the winter ceromonies were over; there was precious little daylight yet alone sunshine; and the people must have commonly been very short on supplies of food. There could not have been a better time in the year for something or someone to lift the spirits of the people. And what better lift could there be than for a pronouncement by an Elder or other authority person that, because the horns were only slightly tilted, the eagerly and perhaps desperately awaited eulachon run was sure to be good—a placebo pronouncement. Only many years later would after-dinner conversationlists sometimes recall that, if the truth were told, there were a few years when the forecast was actually not very good. ◊

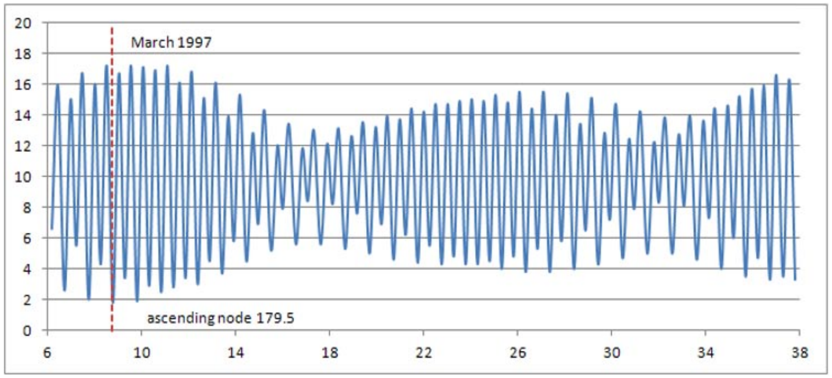

Figure 9A: Tide (feet, Port Hardy) for March 1997 following the new moon (conjunction) on March 8 (PST). The moon's orbit is inclined upward in December and downward in June with practically no inclination in March [crescent has average tilt for time of year]. The new moon is close to perigee.

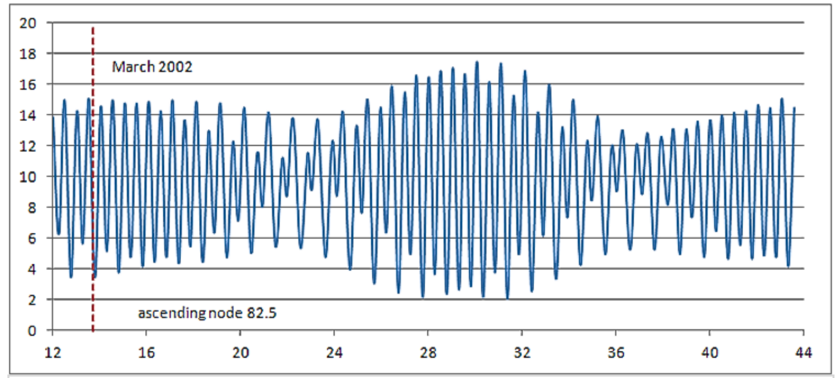

Figure 9B: Tide (feet, Port Hardy) for March 2002 following the new moon (conjunction) on March 13 (PST). The moon's orbit is inclined upward in September and downward in March [crescent has high tilt for time of year]. The new moon is close to apogee.

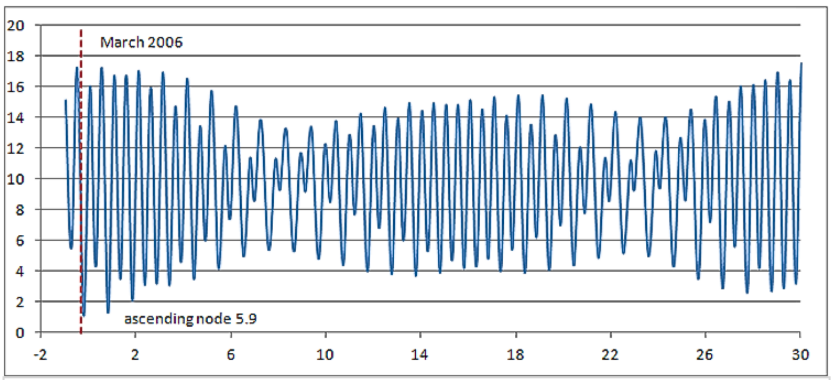

Figure 9C: Tide (feet, Port Hardy) for March 2006 following the new moon (conjunction) on February 27 (PST). The moon's orbit is inclined upward in June and downward in December with practically no inclination in March [crescent has average tilt for time of year]. The new moon is close to perigee.

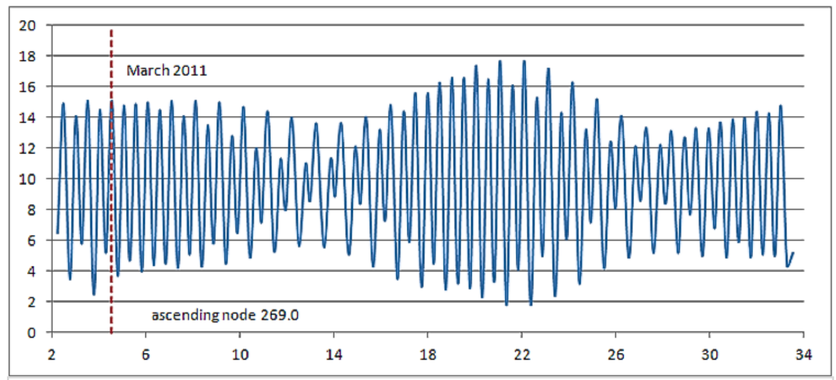

Figure 9D: Tide (feet, Port Hardy) for March 2011 following the new moon (conjunction) on March 4 (PST). The moon's orbit is inclined upward in March and downward in September [crescent has low tilt for time of year]. The new moon is close to apogee.