



Action: numeric metamorphosis of a curve through the PPFM spreadsheet

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The way of nature

If one way is better than another, it is surely the way of nature (Aristotle). This thinking defines the essence of the optimization you always seek: to offer the most efficient solution to a definite problem. The most efficient solution is to know how to apply optimization. Thus, both biologists, economists or engineers, by applying optimization, aim to achieve maximum efficiency, and this goes beyond, and far beyond the description and adjustments of curves or mechanisms (Sutherland, 2005).

Optimization, that is, the application of the first principle, also known as action, it is the key to understanding behaviors, or reasons of choice made by wise nature, when optimizing their costs (Ribeiro, 2017; West et al., 2001, 2004; Sutherland, 2005; Zha et al., 2019; Zhao et al., 2018).

Energy cost is one of the most critical, reason for modulating the behavior of organisms (survival and reproduction) (Bejarano et al., 2017; Tomlinson et al., 2014; Wilson et al., 2006). Another cost factor is time (Gleiss et al, 2011). Thus, the determination of the energy-time cost enables the definition of the action (Rosen, 1984; Grandpierre, 2011c).

This brings us back to optimization, which makes it possible to set the path by prioritizing efficiency, which minimizes energy and time costs (Rosen et al., 2008).

Exergy and action almost equal, while exergy ends in equilibrium (Rosen et al., 2008), action in biology seeks to prolong life, moving away from the equilibrium that would lead to death (Grandpierre, 2011c).

Applying action allows measuring the magnitude of efficiency losses and their location in time, favoring better insights to define the cause or essence of the challenge or problem, minimizing negative impacts, either on the organism itself or on nature. Thus, the action promotes sustainability (Grandpierre, 2012).

The principle of action accommodates all the laws of physics (classical mechanics, hydrodynamics, electromagnetism, thermodynamics, theory of gravity and even quantum physics) and is defined as: “A fundamental law can be considered as a first principle, if and only if all of fundamental laws of the given branch of natural sciences can be derived from it ” (Grandpierre, 2011a).



According to Grandpierre (2011b), the principle of action directs biological processes to the principle of greatest happiness. It also reinforces that this state of satisfaction is not a moment, but a whole. Hence, the need for these processes to be kept as far and as long as possible from thermodynamic equilibrium (biological death) (Owen-Smith, 2005).

The greatest success for greatest happiness is precisely to maximize the return (profit) of the path (time), to be biologically as advantageous as possible from the beginning to the end of the sum of all energy investments made in this life story (Zee, 1986; Rosen 1986; Grandpierre 2011c). Such a procedure justifies the cost function being fully consistent with the biological pathway (Rosen 1986).

Exactly the optimization of this product (energy x time) is the whole essence of life (cost function), which in physical language would be the principle of greatest action, but in biological terms is defined as the principle of greatest happiness, being one of basis for unification (Grandpierre, 2007, 2011abc).

Although the first principle is valid for both sciences, the behavior is quite different, since physics is moving towards equilibrium (end point), whereas biology does not, reason for the latter to invest work (energy) against equilibrium (optimal end state) (Grandpierre, 2007).

The Quanta Way

According to Feynman's interpretation, quanta explores all possible paths, between the beginning and the final state, through virtual interactions (Feynman, 2005; Feynman et al., 2010; Mathew, 2014). This wisdom of how much is manifested and measured by the principle of action (energy x time). Interestingly, it presents the same unit of Planck's constant. In this surprising way, the dimension of greatest happiness maintains the same dimension, that is, it always seeks the wisest way to extend and maintain life with quality (Grandpierre, 2011abc).

This allows us to introduce the importance of psychology in the daily decisions of living beings, for example when comparing a stone, a plant, an animal and a human being; in this sequence, we have the most rigid instinct (stone), which only follows one endpoint, even the most flexible, because it relies on less (human) instincts, when attending to whims and not needs, to overreact happiness as much as possible. One of the reasons of our modern civilization finds more disease and tension. This shows a psychological imbalance, lack of limits on behavior, reason for never achieving full happiness, never contentment, loving money, power and success. (Martínás, 2011; Grandpierre, 2011a). This really is a psychological deviation that harms not only being but the whole, making nature groan (Romans 8:22).



Thus, the first principle is fully manifested by the joint participation of physics, biology and psychology as tools for the study of the history of a life as a whole (Grandpierre, 2011c).

Action: explore all possible options and decide the most efficient way! (Grandpierre, 2009). This is taken as a mysterious property adopted also by the quantum mechanism (Garfield, 2009). What is curious is that the long-awaited decision overlap, envisioned by quantum computing, and not just binary (silicon chips), is already common in quantum biology (Arndt et al., 2009; Marletto et al., 2018).

Now it is coherent to understand the energy path taken in photosynthesis, when evaluating all options, decides for the most efficient (Zhang et al., 2015). To think that biology can be better understood through quantum theory, and that life is also a quantum process is new and enigmatic (Ishizaki & Fleming, 2010).

If life is a molecular process, and molecular processes are governed by quantum rules, life is certainly a quantum process (Schwartz, 2013).

The beginning of classical physics is dated from Newton's publications in 1686, based on the laws of gravity and motion. By applying these laws, and by knowing the position and velocity of each object, it was possible to know their past and future, for example, predict the path already traveled and the return of Halley's comet (Chang, 1979). However, microscopic behavior is well differentiated, not accommodating the laws of classical physics, but requiring quantum physics (Feynman, 2005; Feynman et al., 2010).

Similarly, it is possible to observe a transition from classical to quantum biology, which, like physics, is harmoniously and beautifully complemented (Grandpierre, 2018).

But what about the quantum world that is not detected in the classical world? The cleverness! (Gonga et al., 2018).

In order to elucidate the cleverness or quantum intelligence it is appropriate to apply the analogy attributed to Gregory D. Scholes (Toronto University): every day having to choose to return from work to his home, having the opportunity to choose three path options, but always use only one, and never wonder if the other two options could be more timely (<http://manashsubhaditya.blogspot.com/2013/03/the-spooky-world-of-quantum-biology-new.html>). In the quantum world it is not necessary to say its location, so the three routes are evaluated at the same time, and the most efficient and fastest will be chosen (Schwartz, 2013).

As a practical example of such a comparison, we cite studies of diesel engines that combine classical physics with quantum mechanics, allowing for improved understanding and interpretation of the path in which energy is transferred to do useful work, and more with the advantage to describe the work as good, not too good,



worrisome, bad, etc. And all this by using a numerical value measured in quantum dimension, which essentially assesses how efficient the useful work was and at what time (Girtler, 2009, 2011; Girtler et al., 2011).

Using the same analogy, one can think of living organisms and classify growth work as great, good, not so good, bad, etc.

Therefore, what is evaluated is not only a growth curve that fits the data, but an optimized evaluation, expressed through a specific numerical value, such as the energy x time dimension, which in turn is adopted in quantum mechanics and that characterizes Planck's constant (Girtler, 2009ab).

Moreover, the system by presenting energy x time coordinates, allows to be represented graphically, and its respective area represents the principle of action, that is, the integral of useful work at each moment of time (Girtler, 2008, 2009ab, 2011).

Since energy can only be evaluated at the moment it is transformed, it is at this very moment that useful work is measured that allows the growth of a living organism. Thus, this is the relationship between kinetic energy and work (Girtler et al., 2011).

During the growth process of a living organism, through the principle of action, it is now possible not only to characterize its growth, but mainly to measure the energy conversion into the useful form of labor that was effectively destined for growth (Johnson, 1992).

The biology version of the principle of action allows us to enter quantum biology in a practical and accurate way both numerically and graphically. From the data of the growth curve, the path of growth (action) is determined by quantum processes and decisions (Grandpierre, 2002).

The principle of action allows a deeper meaning and better understanding of the growth process of living beings, not only in accommodating a curve, but now it is possible to numerically evaluate the intelligent route that optimizes the development, or rather the strategy found in virtual interactions, and all this at the quantum level (Grandpierre, 2002; 2008).

From the above, applying the principle of action, it is possible to observe the quantum effect on a macroscopic scale, by adjusting the growth curves of living organisms, allowing the interface between quantum physics and biology (Arnold et al, 2009; Brookes, 2017).

Thus, through quantum evaluation in biology, it is possible to find the route chosen to reach the final goal, among several possible paths, and all hidden within the growth curve (Brookes, 2017).



The quantum-level information and decision-making process allows for the implementation of the best route for the growth of a living organism (Lambert et al, 2012; Brooks, 2017). From the action principle (quantum information) it is possible to define quantum biology in the growth process (route), showing a new window for understanding this mystery (Wu et al., 2012). “Indeed, growth has often been considered the central mystery of life” (Bertalanfy, 1952, p 136).

“Action is an integral (sum) of all energy changes during the corresponding time intervals, constituting a cost function formulation and a mathematical optimization problem” (Grandpierre & Kafatos, 2013). This definition for action is so timely and perfect that it comes close to a poem, because, it is compact in structure, eloquent in cadence, and very lucid (Zee, 1999, p. 103).

Just as, in order to manufacture a particular commodity, a corresponding investment is required, which will represent its cost of production, biologically, if it is necessary to invest a great deal just to survive, there is probably too little left to develop. Thus, it is precisely the fact that the sum of all the energy changes of each consecutive time interval in relation to the total period enables the process to be considered biologically as an energy investment (Johnson, 1992).

The ideal would be the minimum to survive and the maximum to prosper, which is nothing but the most efficient way. The challenge of every living organism is considered a problem of optimizing all the energy invested in each consecutive time (Grandpierre & Kafatos, 2013; Bridson & Gould, 2000).

The theoretical biology

Definitely, a living organism wisely selects the best endpoint through its activities and choices according to the greatest action principle (Grandpierre, 2009).

Recalling that action presents the energy x time dimension, summarizing comprehensively, but very profoundly, all the completeness to preserve and seize every opportunity in life (Grandpierre, 2002).

Therefore, every living being, of course, will work to prolong its existence as long as possible. That is, nothing more than maximizing time. But living is not enough, there is a need for vitality with quality of life. Thus, it is also mandatory to maximize the first term of the product “energy x time” (Grandpierre, 2008).

There is not only a simple energy x time product, but a clear, coherent and relevant definition for applying concepts of physics in biology, which boils down to the principle of greatest happiness, incorporating for its full understanding, in addition to the concepts of physics and biology, also psychology (Grandpierre, 2011).



This makes the reason for the term investment in biology coherent, because through action as the integral (sum) of all the energy invested at each moment of time, it seeks not only to prolong life, but also quality of existence, which is summarized in a single value (action) (Johnson, 1992; Grandpierre, 2008).

It thus enters into a theoretical biology in which every living organism is governed by laws, which in physical terms is equivalent to the greatest action principle (Grandpierre, 2007).

This would be the basis for a theoretical biology to approach theoretical physics, but with distinct objectives in relation to the end point (Grandpierre, 2002). Physics is unchanging, but biology naturally seeks the most promising (happiness). This can be very well illustrated by releasing in each hand a dead and a living bird from the top of a tower. Regarding the first case, its trajectory is similar to a stone, which obeys without question the laws of physics, in a trajectory of free fall until it reaches the ground. However, the live bird, seeking life, in the shortest possible time and effort seeks a safe place away from the ground (Grandpierre, 2011).

It is now possible to understand the great enthusiasm of physicist Grandpierre to devote so many papers to the principle of action (Grandpierre, 2002; 2007; 2008, 2009, 2011abc; Grandpierre & Kafatos, 2012; Grandpierre & Kafatos, 2013). Defending an autonomous but physically based biology to the point that it is necessary to enter quantum physics to justify the path of optimization (Grandpierre & Kafatos, 2013).

Action would be, consistently, the wisest way to preserve and energy available between the beginning and end time, which rules the path of every living organism. Thus, even a unicellular organism facing challenges to survive is obliged to optimize the problem through anticipatory and contemplative procedures (Mayne et al., 2015), based on past information and experiences, or even when having to find solutions to new challenges (Ben-Jacob, 2009). Even for single-celled organisms, they are considered intelligent decisions and behaviors (Mayne et al., 2015; Ben-Jacob et al., 2004).

While physics is an exact science, biology is autonomous. Thus, it has the ability and independence to present spontaneous decisions, being defined by Grandpierre (2007) as the principle of greatest action. Even unicellular organisms demonstrate problem optimization, with anticipatory and contemplative behavior (Ben-Jacob, 2009).

Action is the integral (sum) of the energy changes observed at each time interval and can be considered as a cost function that aims to optimize a problem, which is very coherent in biological terms (Grandpierre, 2013). From this fact, the sum of all energy changes in consecutive time intervals in relation to the total period, biologically, can be considered as the product of energy investment \times time investment (Grandpierre, 2013).



In this way, action defines a numerical unit that affects both vitality (as high as possible) and longevity (as long as possible), a fact naturally desired by all living beings. Such a procedure therefore requires living beings to maximize both time and energy, which is defined by the principle of maximum action (Grandpierre, 2007). Emphasizing that a falling stone, with no option, meets the physical principle of least action, a bird in the same falling condition will spontaneously perform the greatest action to survive and thrive, but with the consistency of minimal energy investment (Johnson, 2006). Such a procedure is compatible with being considered as a function of optimizing the most valuable resources for life (energy and time), paving the way to enter quantum biology (Grandpierre, 2013).

The intelligence of action

Discussing action is something mysterious, so be careful when venturing into this area. For example, Zee (1999) describes “Where the action is not”; at the same time, respect and prudence are observed for the theme, that is, showing the importance of this subject. Interestingly, von Bertalanffy in 1952 already indicated that more attention should be devoted to understanding the principle of action in biology.

But what is so beautiful about the principle of action? Perhaps it is because it has a compact structure, which allows measuring not a fixed moment in time. But because it is associated with the whole, it measures change. Thus, a story is summarized only in a single value, which offers perfect lucidity of an event (Grandpierre, 2008).

Clearly, in Newton's view the object is focused at a particular instant of time. This resembles a photographic camera that with one click freezes time at a very particular moment. Thus, according to Newton's laws it is permissible to define a later moment by knowing the velocity and position of the previous moment (Zee, 1999).

But if a video camera was used instead of a photographic camera? We would not have just a moment (photo), but a movie, the action! Now, in this way, action allows us to describe the whole path of an object whose history is summarized in a single number. Really, magical and admirable (Nagao & Nielsen, 2017; Zee, 1999).

Therefore, the fascination and grandeur of the action lies in its ability to describe a history with a number, which considers not only all possible paths between two points, but also all the ways to travel them, but which at the end of the story only the one who optimizes resources is the one who defines action (energy x time) (Johnson, 1992; Nagao & Nielsen, 2017).



It is obvious that each story will be dependent on the circumstances. In this way, the story (film), compressed by the action principle can be represented by a numerical value, flexible and dependent on challenges and new circumstances (Zee, 1999).

The point here is not to define the most favorite story, but the most favorable one. This is the concentrated essence of life, in its simplest, most perfect, pure and elegant form, allowing physics to clarify the path of biology, the daily practice of action in which a living organism optimizes energy and time (Grandpierre, 2011), it is similar to the business man who seeks to maximize profit by following the most advantageous path (Zee, 1986, p. 107). From this similarity comes the possibility of comparing the principle of action with a cost function (Rosen, 1986).

Therefore, the key that defines all this numeric metamorphosis and makes it possible to evaluate the system represented from its growth curve is action, evaluated as the integral of kinetic energy ($KE = m.v^2 / 2$) in relation to time (Rudnicki, 2009). This results in the history of all useful work and its changes over time, which allows us to characterize the growth of a living organism and its actions to define the best path by being subjected to unexpected and continuous challenges, defining its growth curve (Grandpierre & Kafatos, 2012; Owen-Smith, 2005).

Quantum biology

All living things are made up of molecules, which in turn are described by quantum mechanisms. Thus, all biology is the result of quantum properties (Lambert et al., 2013; Marais et al., 2018).

Therefore, it is in quantum mechanisms that biological enhancements are defined to enable better gains, advantages and efficiency over the challenges encountered in the real battlefield of life, and all with direct impact on the macroscopic world (Arndt et al., 2009; Neill et al., 2012; Marais et al., 2018).

The action principle is the key to assessing growth to its fullest, as it evaluates time and energy simultaneously. That is, an organism to grow requires optimizing the time and energy received in life (Bridson & Gould, 2000; Wolynes, 2009).

This biological autonomy is initiated in a quantum process, and always seeks the best solution (optimization) (Sutherland, 2015). Thus, again and in fact, if there is a better way, it will surely be the path chosen by nature (Aristotle).



Feynman reports that quanta explore all possible paths between the start and end state (Feynman, 2005, Feynman et al., 2010). In the quantum world there are tricks to promote optimization, such as kicking a ball against a wall and disappearing and appearing on the other side (Ogborn et al, 2006; Moore, 2004).

So, via the quantum process, it is possible to simultaneously explore all possible routes and only choose the most efficient path (Bridson & Gould, 2000; Offord, 2019). Process that on this scale is defined only by complex mathematical language, compatible only with quantum mechanics, challenging common sense (Chung, 2015; Lehman & Persinger, 2015; Neale, 2019; Offord, 2019).

Living beings, in their essence governed by molecular processes, such processes being operated by quantum rules. Therefore, life is governed by quantum processes (Schwarz, 2013).

In the physical system, the initial state defines the end. However, in the biological system, the final state presents autonomy, allowing the living being the right of selection (Grandpierre, 2008).

This new way of interpreting physics makes it simple and elegant to connect biology to quantum principles through the principle of action (Grandpierre & Kafatos, 2012).

The principle of action is defined by a number representing an integral value, providing a dynamic basis between the quantum system and biology. Thus, when comparing the action to a cost function, the most fundamental is the optimization of the invested energy and the invested time, being an intelligent process (Grandpierre, 2008).

Thus, for a deeper understanding of this biological mystery, the interpretation of quantum physics is inevitable (Bridson & Gould, 2000; Grandpierre, 2009).

Any living organism naturally aims not only for survival but also quality and duration of life as priorities. Therefore, it is necessary to move away from the physical thermal balance, which would be death in biology. Due to this fact, action represents a numerical unit that makes it possible to measure the essence of quality of life through the best possible use of life's most precious resources (time and energy), culminating in the principle of more action (Grandpierre, 2009).

This better quality of life combined with the longest possible duration involves applying useful work that will oppose balance to allow as far and as long as possible. By this procedure, living organisms, through their autonomy, maximize their survival with quality of life by intelligently investing useful work to optimize energy and time (Grandpierre & Kafatos, 2012).



The connection of quantum mechanics and biology is definitely allowed by the action principle to enter the deepest level of physics, elevating biology to a quantitative science (Westerhoff et al., 2009; Grandpierre, 2009).

According to quantum mechanics, a particle does not define the best route without first exploring all possible trajectories (Moore, 2004). Similarly, a living organism by the principle of maximum action chooses the best route from as many paths as possible. Therefore, this is the relationship between the biological principle of action and quantum mechanics, which justifies the dimension remaining the same (energy \times time) (Grandpierre & Kafatos, 2012).

Thus, the principle of action provides an excellent way to analyze the energy efficiency involved in the intelligent decisions of biological systems. This allows new insights to understand why the route chosen is the most efficient, opening up a new area to apply sustainability by maximizing energy potentials while minimizing negative impacts (Rosen et al., 2009).

In our geological age (Anthropocene) the direct influence of man in relation to climate change and environmental degradation is evident. The demand for our best and highest quality of life is making the quality of life of all living species on our planet unfeasible, to the point that many do not even have enough to survive. Thus, the fruit of the principle of human action is making the principle of action of other living organisms unfeasible (Johnson, 1992; Tomlinson et al., 2014; Owen-Smith, 2005).

We are in a moment of transition from the conventional silicon chip (bits) to the quantum computer (qubits); binary limitation for all possible overlaps (Garfield, 2009). This scenario has long been realized by nature with almost 100% efficiency, such as photosynthesis (Ishizaki & Fleming, 2010; Lambert et al., 2013; Panitchayangkoon et al., 2010; Zhang et al., 2015).

Quantum biology emerges to unravel mysteries still pending clarification, such as intelligent and anticipatory mutations by bacteria and fungi (Jabr, 2012; Garfield, 2013; Mayne et al., 2015). Thus, the defense and decisions of these microorganisms occur at a quantum level, which is why we are weak in fighting them in the macroscopic world.

Quantum mechanical processes are reported in birds using geomagnetic navigation. And also, in enzymes, vision, smell, and neurons (Cha et al., 1989; Brookes, 2017; Fisher, 2015; Fleming et al., 2011; Lambert et al., 2013). Thus, all the phenomena involved in maintaining and extending the life of an organism (metabolism, regeneration, growth, homeostasis, etc.) represent the mystery of cost function property (Grandpierre & Kafatos, 2012; Lengauer, 2001; Rosen, 1986).



Practical application of action: PPFM spreadsheet

The PPFM (Practical Program for Forces Modeling) spreadsheet is a user-friendly software that facilitates curve fitting without the need for a thorough knowledge of math (Fig 1).

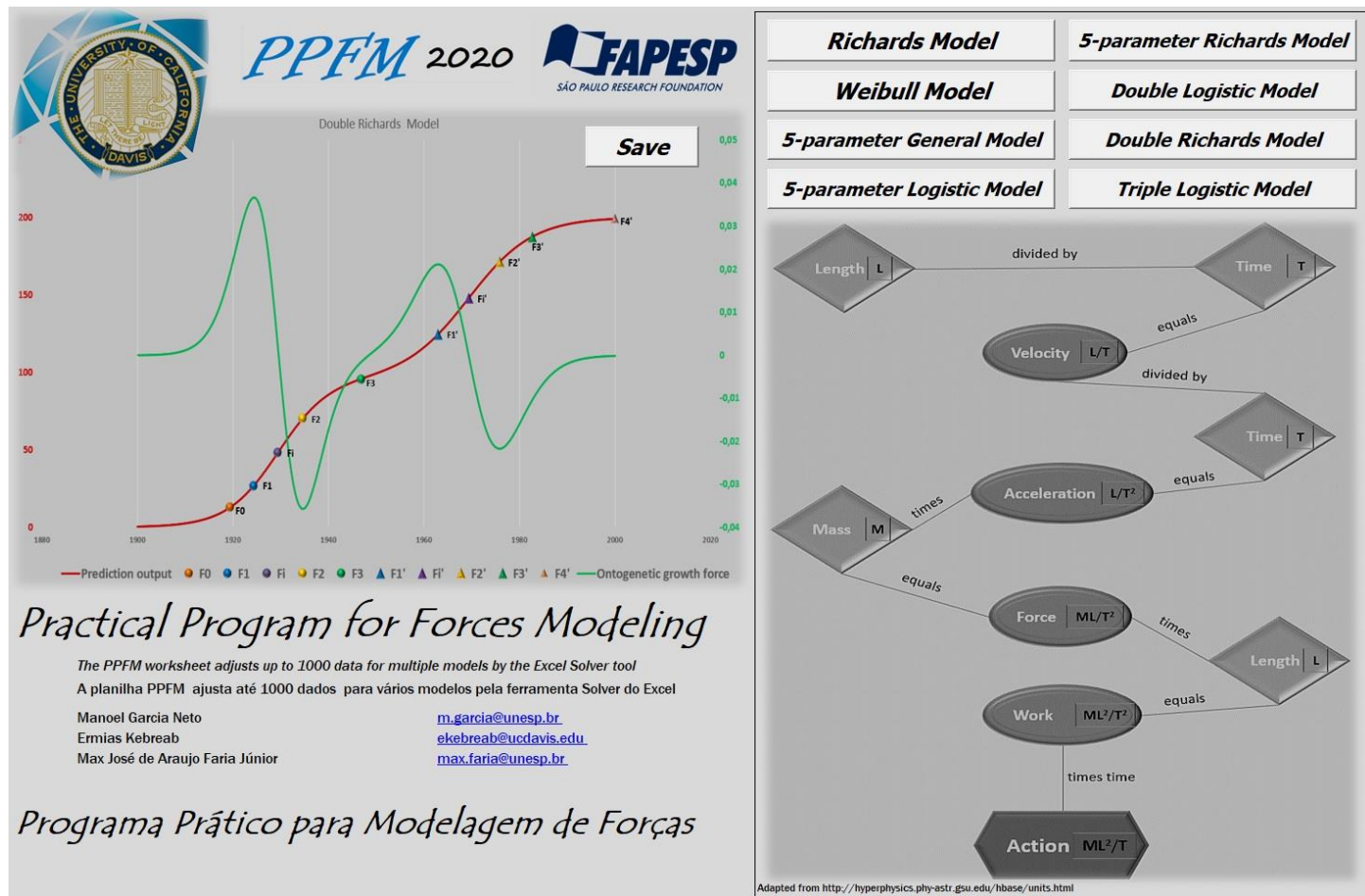


Figure 1. The PPFM (Practical Program for Forces Modeling) spreadsheet.

The PPFM spreadsheet is based on Microsoft-Excel-Solver, which, being commonly used on most computers, facilitates the understanding and application of the necessary operations, since it has a simple interphase (Nemestóthy et al., 2018). In addition, the PPFM spreadsheet results, provided by the Excel editor and their graphs, are straightforward and easy to understand, making adjustments practical and clearly interpreted (Tjørve & Tjørve, 2010; Archontoulis & Miguez, 2015).

The better characterized the life span of a living organism and its different phases, the better the action analysis will be (Baty & Delignette-Muller, 2004; Lambertini et al., 2010; Zwietering et al., 1990). In other words, the more precise the definition of the trajectory (curve), the more appropriate is the value obtained for the action,



which provides a powerful tool for condensing information about dynamic systems and their whole, and most importantly, which path was chosen in infinite possibilities to reach the endpoint (Grandpierre, 2008).

This privilege is now offered by the spreadsheet PPFM, which unfolds the growth curve in its derivatives, with graphical and numerical visualization of the different phases of the path taken, culminating in the action energy-time dimension, which in short defines the history of a system, and not just a fixed moment of time, allowing to incorporate alternative units to characterize growth (height, length, mass, individuals, volume, density, etc.) and time (seconds, minutes, hours, days, years etc.), that is, biological autonomy (Grandpierre, 2012).

Solver is an Excel add-in that enables nonlinear optimization. The PPFM spreadsheet uses the Generalized Reduced Gradient (GRG) option to adjust growth models. For the solver to operate properly, it is essential to provide coherent and appropriate initial values to the parameters that define the model (Archontoulis & Miguez, 2015; Kuhl et al., 2003; Strathe et al., 2010). The quality of this procedure is visually confirmed by the immediate graphical adjustment and observation of the residual analysis, predicting possible model fit violations (Strathe et al., 2010) (Figure 2), and to compare the performance of models in terms of goodness-of-fit indicator: residual standard deviation, adjusted coefficient of determination (R_{adj}^2), proximity to the truth (Akaike information criterion / AIC) or probability of truth (Bayesian information criterion / BIC) (Wit et al., 2012).

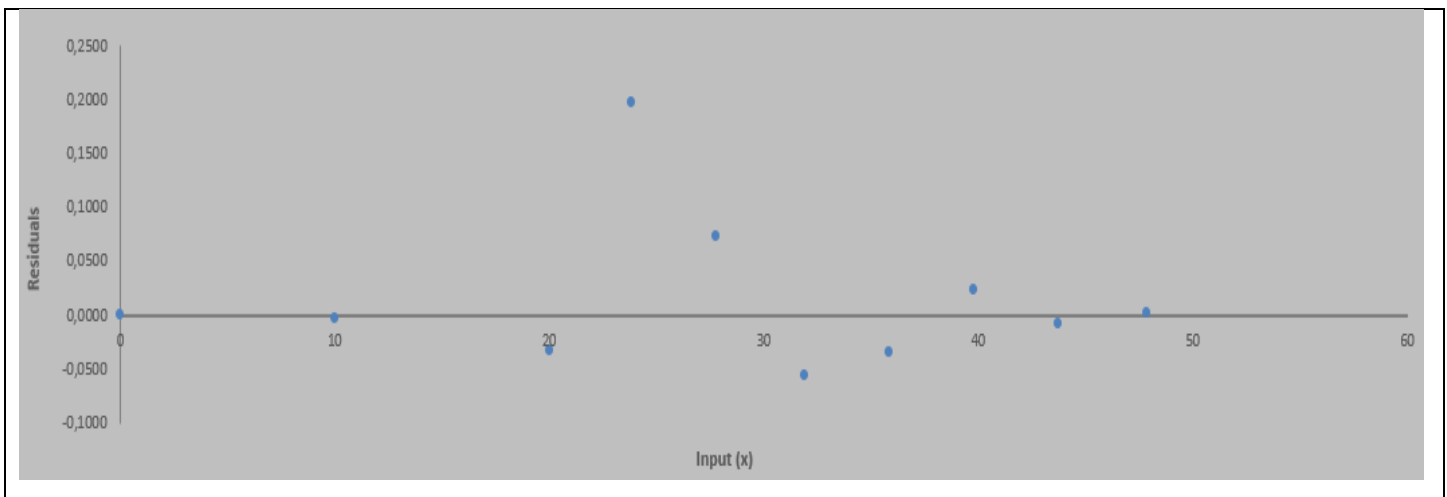


Figure 2. Residue analysis of a graph adjusted by the PPFM spreadsheet.

For this, the PPFM tool uses the Excel solver supplement, which through iterative optimization processes, allows to find the most appropriate parameters that adjust the growth curve. This process is performed by multiple loops that are repeated until the best possible data accommodation is obtained, as it minimizes the sum of squares of the function (Figure 3).

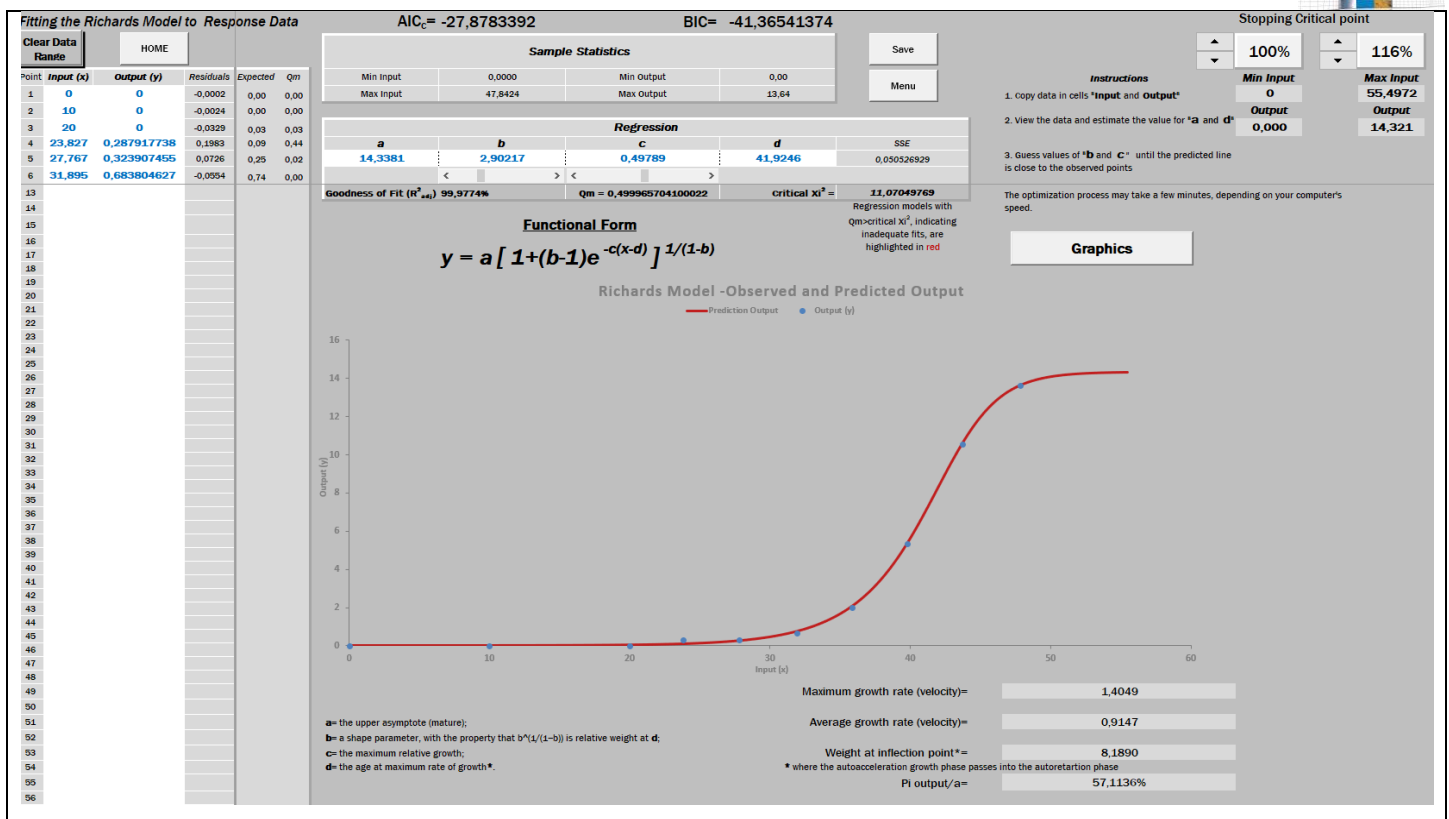


Figure 3. The Excel solver add-in, which through iterative optimization processes, allows you to find the most appropriate parameters that adjust the growth curve.

Sigmoid curves are often used to describe growth dynamics, and the most widely used models are: Richards, Gompertz, Logistic and Weibull (Birch, 1999; Zullinger et al., 1984; Hernandez-Llamas & Ratkowsky, 2004; Beiki et al., 2013; Panik, 2013; Yang et al., 1978; Tjørve & Tjørve, 2017; Kaplan & Gürcan, 2018). For a better understanding of this form of analysis it is possible to derive the curve to characterize velocity (1st derivative) and acceleration (2nd derivative) (Figure 4) (Buchanan & Cygnarowicz, 1990; Bentea et al., 2017; Lambertini et al., 2010; Shahin et al., 2013; Szparaga & Czerwińska, 2017; Szparaga & Kocira, 2018). Up to this point, we are still in classical biology that fits in very well with classical physics, defining the different phases of a curve when evaluating the force involved in growth ($F = m.a$).

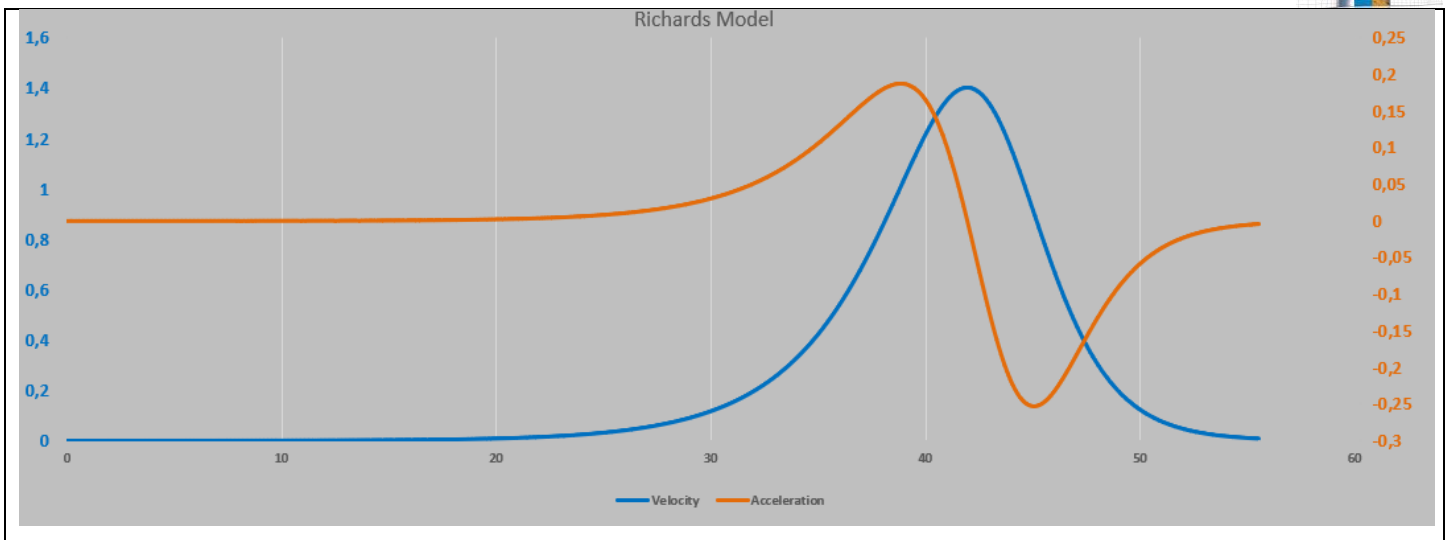


Figure 4. Velocity (1st derivative) and acceleration (2nd derivative).

The mechanistic model and its derivatives (1st speed; 2nd acceleration) should represent the growth process at the core of its mechanism (Eby et al., 2010; Tabatabai et al., 2005, 2013a; West et al., 2001). Therefore, among the candidate models to compose the PPFM spreadsheet, the function should be explicitly defined. Also, to allow for greater flexibility, the function should have a free inflection point (Cai et al., 2016; Vrána et al., 2019; Zeng & Wan, 2000), or even more inflection points (Ali et al., 2004; Bock et al., 1973; EL Lozy, 1978; Narushin & Takma, 2003; Shahin et al., 2013). To this end, alternative models are offered, allowing to capture the dynamics of growth, which involves its complexity and peculiarity (Figure 5) (Ahmadi & Mottaghtalab, 2007; Bebbington et al., 2009; Brown et al., 2007; Cao et al. 2019; Chattopadhyay et al., 2019; Di Crescenzo & Spina, 2016; El Lozy, 1978; Koops, 1986; Gottschalk & Dunn, 2005; Koya & Goshu, 2013; Kuhl et al., 2003; Ji & Fang, 2015 ; Moate et al., 2004; Tabatabai et al., 2005; Tjørve & Tjørve, 2010; Tsoularis & Wallace, 2002; Wan et al., 2000; Windarto et al., 2018).

<i>Richards Model</i>	<i>5-parameter Richards Model</i>
<i>Weibull Model</i>	<i>Double Logistic Model</i>
<i>5-parameter General Model</i>	<i>Double Richards Model</i>
<i>5-parameter Logistic Model</i>	<i>Triple Logistic Model</i>

Figure 5. Mathematical models adopted by the PPFM spreadsheet for curve fitting, allowing to capture the dynamics of growth, which involves its complexity and peculiarity.



Lag time duration is of great importance, for example, in defining the warranty time of food products (Baranyi et al, 1993; Baranyi & Roberts, 1994, 1995; Broughall & Brown, 1984; Dalgaard, 1995; Gibson et al., 1987, 1988; Jones & Walker, 1993; Koutsoumanis, 2001; Halmi et al., 2014; Legan et al., 2002; Lopez et al., 2004; McClure et al., 1994ab; Membré et al., 1997; Taoukis et al., 1999; Teleken et al., 2011, 2018). The PPFM spreadsheet presents the point F_0 as delay, being a new alternative to define the lag time end (Kyurkchiev & Iliev, 2016; Swinnen et al., 2004), allowing to measure the duration of this phase accurately, among others (Figure 6).

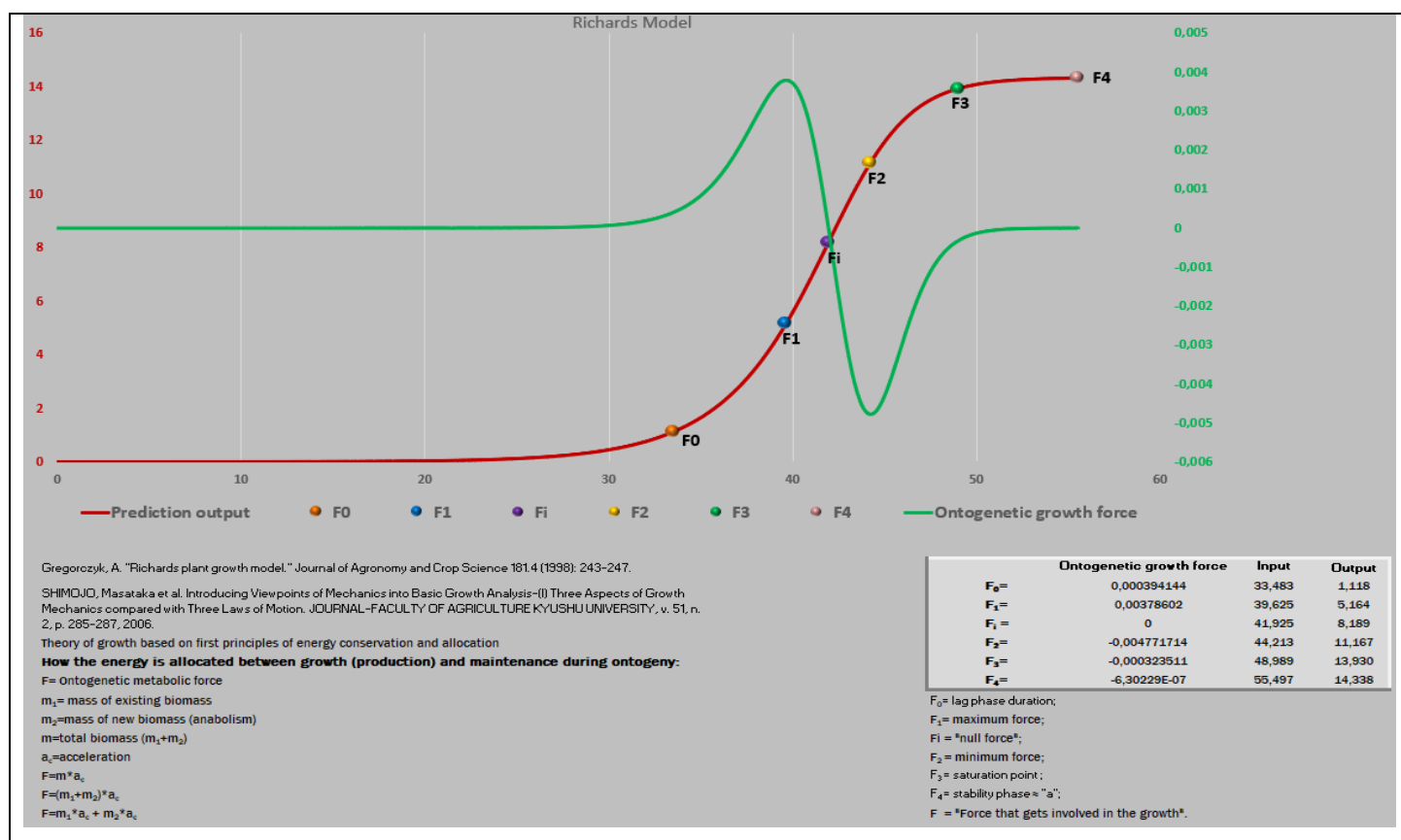


Figure 6. Unfolding of the phases of a growth curve, applying Newton's second law ($F = m \cdot a$) to define the distinct phases that characterize a growth curve.

The estimated values of each parameter should be based on the best visual quality of the graph (curve) that represents the model (Heinen, 1999; Marušić et al., 1994; Strathe et al., 2010). Thus, these initial values (guess) should be as coherent as possible to promote convergence and will allow successful solver adjustment by their successive iteration processes (Archontoulis & Miguez, 2015; Tsoularis & Wallace, 2002). More appropriate values can be obtained from previous studies (Narushin & Takma, 2003).

The biological principle aims at an optimal output, which in turn is validated by the action, as measured by the PPFM spreadsheet that clarifies this new perspective of the application of the laws of physics in theoretical



biology for more longer life and quality (Greatest Happiness). The PPFM worksheet is offered as a tool for assessing useful work (action) against the respective invested lifetime of a living organism, which in turn characterizes its most efficient journey (Johnson, 2006; Grandpierre, 2008).

Thus, what we have then is the PPFM spreadsheet that allows validating data with biological interpretation, compatible with the cost function (time invested x energy invested = action) (Grandpierre & Kafatos, 2012; Rosen, 1986) (Figure 7).

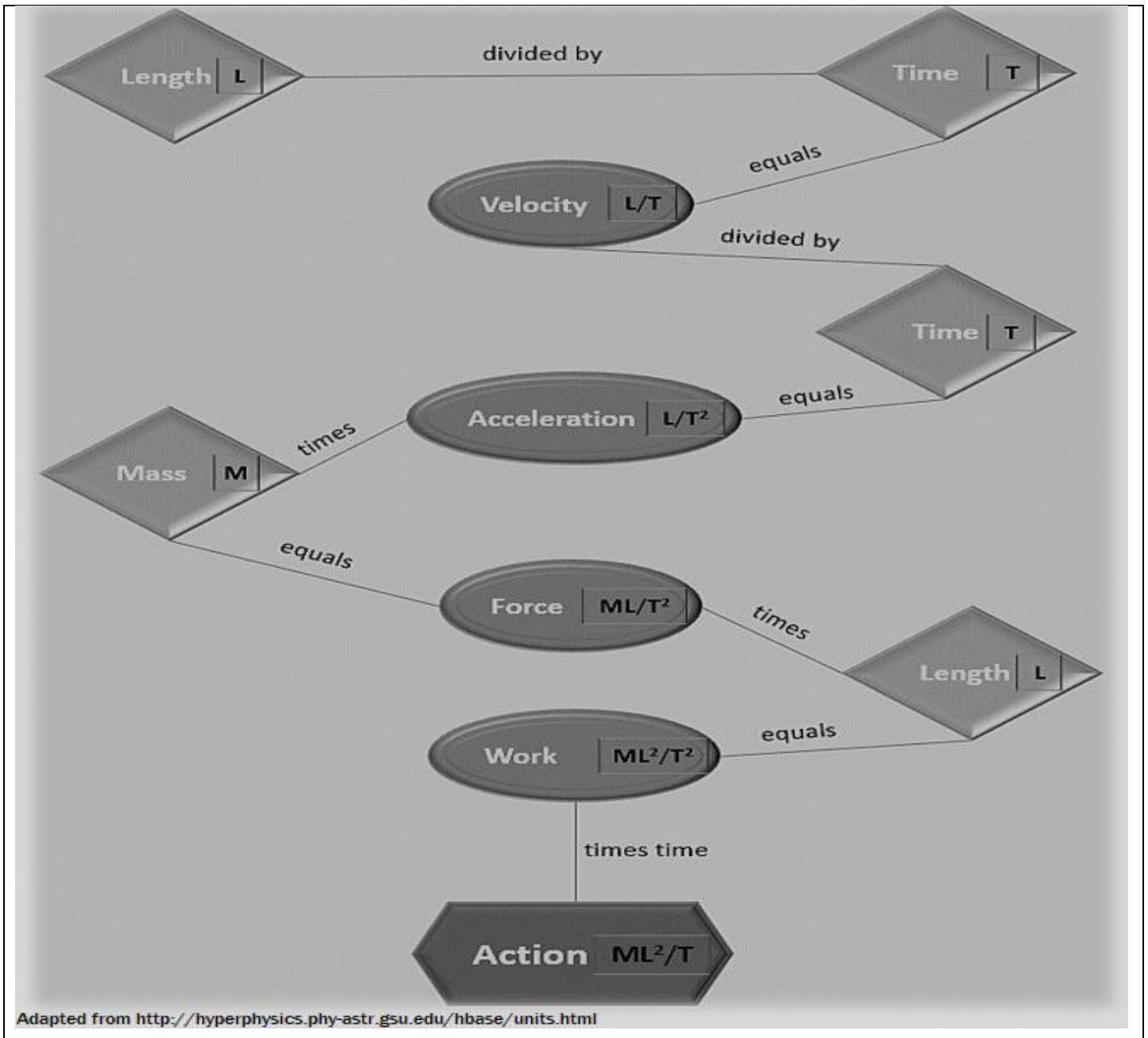


Figure 7. The PPFM spreadsheet unleashes the essence of the growth curve, bringing out the fullness of the action principle.



In this movement for more life, psychology joins efforts to bring out the condition of desire to maximize existence as much as possible. In this, when measuring the action by the PPFM spreadsheet, there is also the measurement of stress (challenges during the history of life), peculiar to all living organisms, which certainly always harms the maximum output but does not prevent it being optimized (Johnson, 2006).

The PPFM tool enables a broader understanding of the path chosen for a living organism to grow, allowing for a deeper, and especially, measurable assessment (Grandpierre & Kafatos, 2012). Thus, the spreadsheet offers a new insight into the interpretation of the time invested and the useful work applied at each moment of the life path of a living organism, in a compact, transparent and easy to handle, favored by graphical and numerical visualizations, with possibility manual or automatic changes.

Here is a deeper understanding of the nature of the curve, not just a simple trajectory, but which from its inception represents phenomena (growth itself), laws (energy and time) and principles (doing everything possible to stay alive and flourish with quality).

From this, the PPFM spreadsheet goes far beyond allowing only a simple curve fitting and its derivatives (velocity and acceleration), but enters and accommodates the laws of physics ($F = ma$ and $KE = m.v^2/2$), which allow us to evaluate the intelligence of living organisms in expressing the best energy and time investment, which is numerically represented by action (energy x time integral) (Figures 8 and 9).

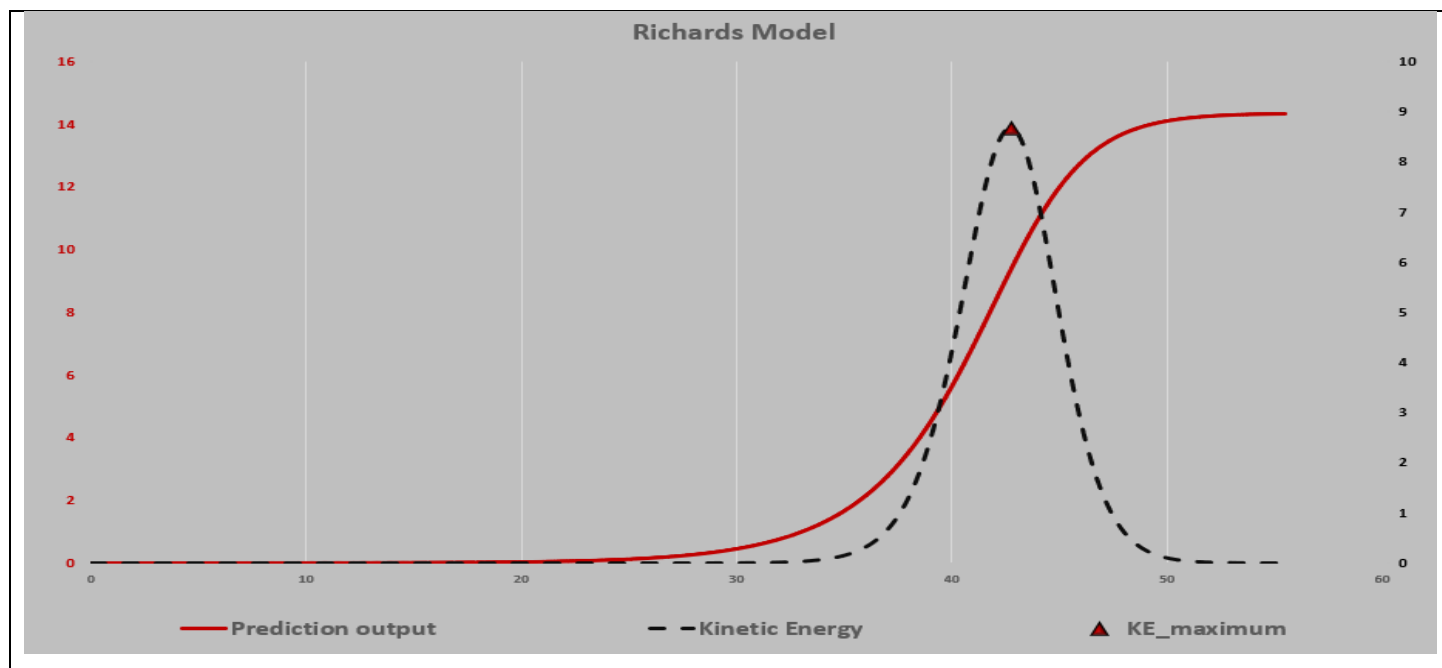


Figure 8. Use of the kinetic energy principle ($KE = m.v^2 / 2$) to calculate useful work for growth.

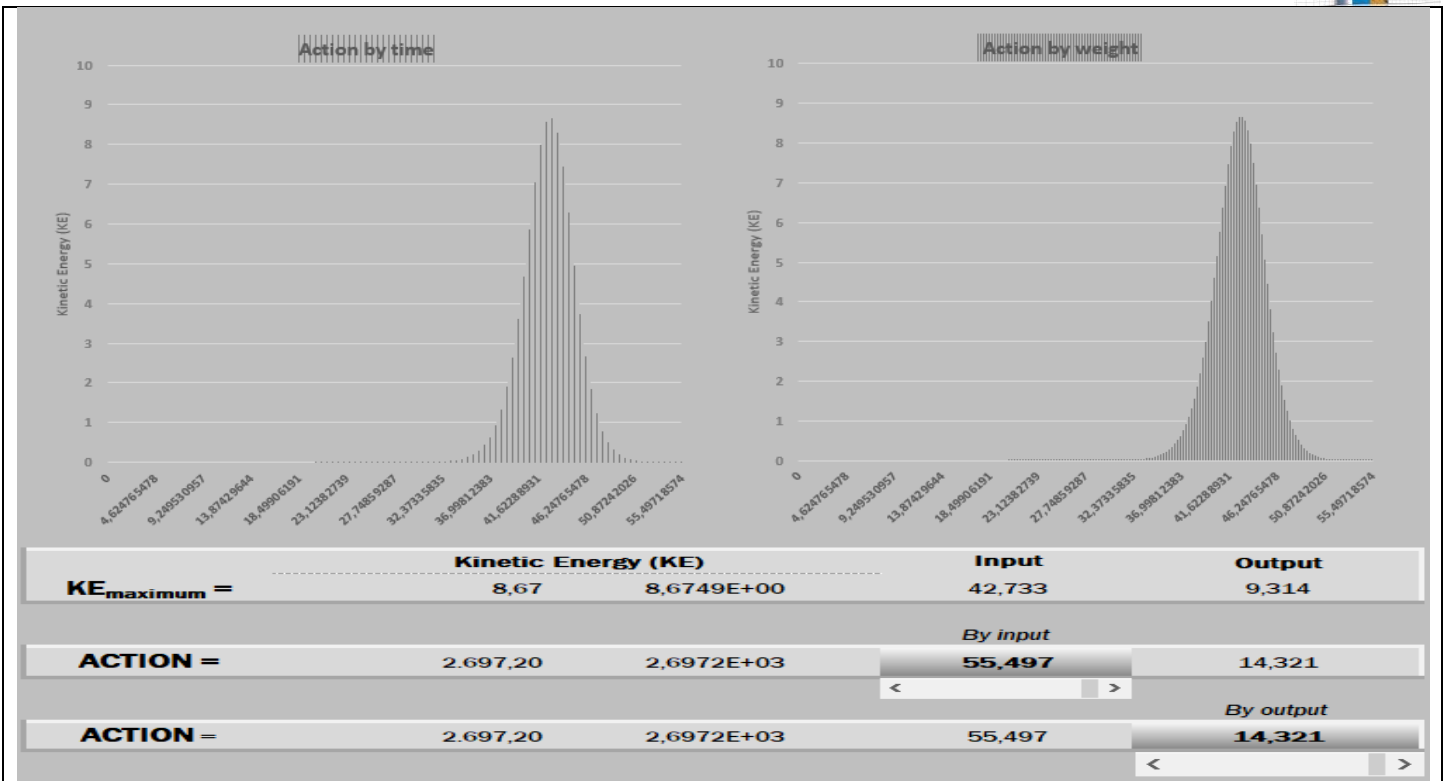


Figure 9. The principle of action is history represented by a single value, simple, compact and elegant.

Yes, it must be understood that what is desired is to complete the metamorphosis of the data (Egg), which at first requires adjusting the curve (Larva) after the derivatives (Pupa), to finally emerge at the height of the metamorphosis through action (Butterfly). This numeric metamorphosis presents intelligence in its decisions, necessary to traverse the life trajectory of a living organism, which requires optimizing the investment of its energy time (Johnson, 2006) (Figure 10).

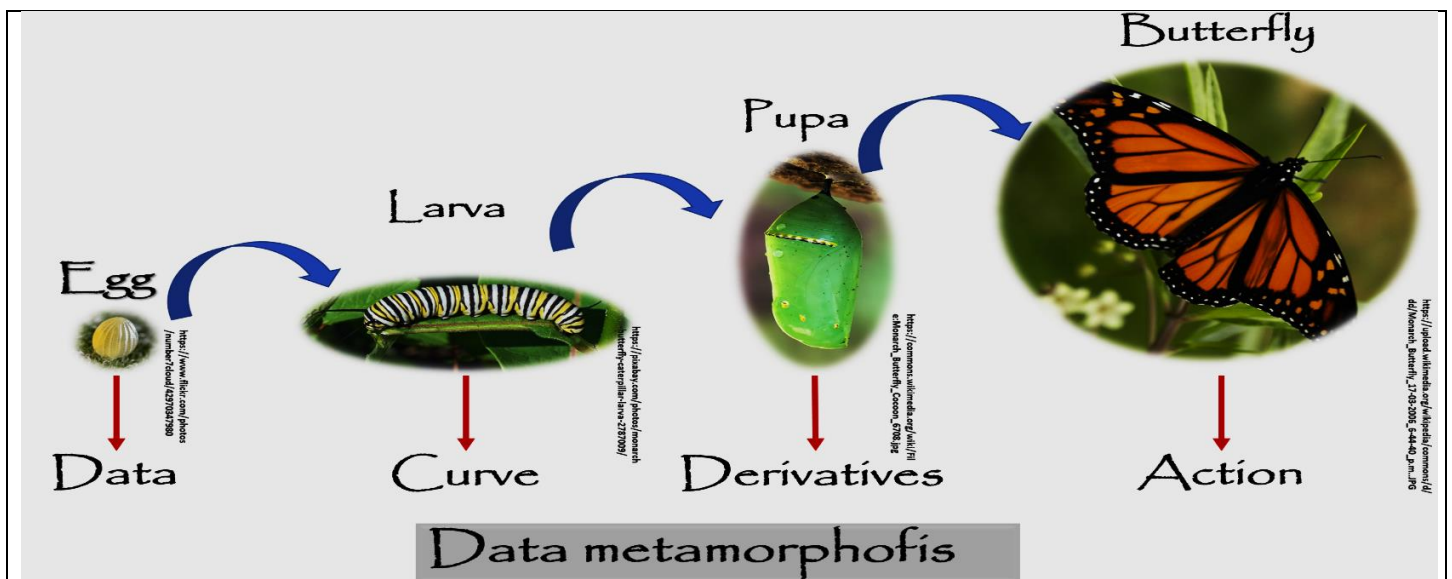


Figure 10. PPFM spreadsheet triggering the essence of the growth curve, that is, the best way to evaluate a model is to allow it to finalize its numeric metamorphosis until it reaches the action principle (energy × time).



This statement proposes a new model that encompasses phenomena, laws and principles, which allows a new perspective, by uniting physics, biology and psychology. Moreover, through the PPFM spreadsheet it is now possible to measure biology by the theories of physics (Grandpierre, 2011b).

But by defining the useful energy applied to growth ($KE = m.v^2 / 2$) and entering the action principle ($J \times s$), the dimension becomes equivalent to the Planck's constant ($J \times s$) (Girtler, 2009ab).

This strong and mysterious link allows us to relate quantum physics to quantum biology, not only for presenting the same dimension (energy x time), but for manifesting the same wise and intelligent behavioral optimization of the chosen path. Based on this new perspective, the proposal of the PPFM spreadsheet is to apply the principle of action in biology (Grandpierre, 2008).

Well-known is the phrase that "all models are wrong ..." (Box, 1979). By analogy, if a pupa insists on continuing just as a cocoon, it is certainly wrong! The right thing is to come out of a butterfly.

Likewise, the model must continue its journey (numeric metamorphosis) to bring out its full camouflaged potential on the curve. Only then can he approach the most correct one (Zee, 1999).

What would be the route of this journey? The first few steps have already taken, and it was exactly extracting from the model its first derivative (velocity) and second derivative (acceleration) (Ali et al., 2004; Bentea et al., 2017; McFee et al., 2010; Tabatabai et al., 2005, 2013; Reed & Berkey, 1989; Rosen, 1986). But other steps were still needed:

- 1- Apply Newton's second law ($F = m.a$) to define the distinct phases that characterize a growth curve;
- 2- Use the principle of kinetic energy ($KE = m.v^2 / 2$) to calculate useful work for growth.

The caveat is that acceleration is the velocity of velocity (Zeide, 1993). Thus, speed becomes the major protagonist in both formulas.

Based on the above, one can calculate the action that actually sums up the whole of growth. Thus, the best way to evaluate a model is to allow it to finalize its metamorphosis until it reaches the principle of action (energy \times time) (Grandpierre, 2009).

It is now possible to propose another maxim: A model is closer to the correct one, if and only if, it is finished with the action principle!



But in practical terms, how to extract the principle of action from a model to make its metamorphosis viable? This is exactly the proposal of the PPFM spreadsheet: a new strategy to bring the mathematical model closer to reality, describing the behavior of the biological process, by allowing a better interpretation of the data.

In short, the numeric metamorphosis of the growth curve, since its adjustment, then by its derivatives and finally by unfolding its strength and energy, enables an accurate, useful and practical application. Such steps allow a better look at what was camouflaged in the growth curve, allowing the real knowledge of its route (Grandpierre & Kafatos, 2012).

Therefore, the principle of action allows and reveals the growth behavior of a living organism, summarizing a whole story that accommodates various interactions of favorable and unfavorable factors that always arise in life's journey of being alive (Johnson, 2006).

Thus, the integral energy \times time (action) enables a better understanding of the forces that govern growth, and also, at each moment, to estimate the useful work applied to growth (Girtler, 2011).

So, the action principle becomes an indispensable ally, allowing significant progress as a new modeling tool in curves evaluations, allowing a coherent and more complete, for improving and facilitating the biological interpretation of growth, with objectivity, simplicity and utility (Grandpierre, 2008).

By following a body at every moment of time, and knowing the force that acts to change its speed, it becomes possible to determine its position at the next instant (Zee, 1999). Similarly, by knowing the force acting on alteration of the growth of a living organism allows its expansion to be determined from one moment to the next (Johnson, 2006).

While Newton's point of view is in the body at every interval of time, action focuses on the view of the whole, that is, the principle of action is history represented by a single value, simple, compact and elegant (Zee, 1999; Nagao & Nielsen, 2017).

To know the history of a body it is necessary to know the time. What's more, knowing all the possible paths and shapes that were considered in your journey, but in the end, led to the definition of the timeliest route, promoting its displacement (Johnson, 2006).

The principle of action is history summarized in a number representing the path and also the forms of walking (Zee, 1999). This value is computed as the sum of the kinetic energy of each instant of time, considered for the displacement of a body that allows the most advantageous history (Grandpierre & Kafatos, 2012). What



is striking is that all the principles of physics can be summed up in the extraordinary and compact principle of action (Zee, 1999; Nagao & Nielsen, 2017).

The principle of action, by considering the whole view of a story, evaluates all possible routes and ways to accomplish this journey. Therefore, each story will be dependent on the circumstances and challenges encountered (Grandpierre, 2008).

The action is equivalent to that formulated by Newton's proposals. Only the perspective is different. The action evaluates the whole and not just the part, the complete structure and not a specific moment. But it takes the sum of each moment to define the whole (Ogborn et al, 2006; Zee, 1999).

The mystery of this story is that always the most advantageous one is the one chosen, giving an almost philosophical and almost theological connotation. This is the description of the growth path, which in an extraordinary and compact manner is summarized by the principle of action. Action is neither more nor less than Newton's laws more compactly (Zee, 1999).

Such behavior in biology resembles the path of light in choosing the most efficient path to reach its destination. Interestingly, Fermat's principle (shortest possible time) is a special case of the action principle (Anderson & Hadi, 2019).

Conclusion

The principle of action considers not only all possible paths between two points, but also all possible ways of traversing it, which allows countless stories (paths + ways), but only the most advantageous story will be chosen.

From this, the principle of action (time x energy) becomes the action signature ends with a number, which represents both the path and the chosen way to go through it, strategically maximizing all the resources of this path, making it possible to select the most advantageous story.

Indeed, it can be said that a cocoon hides a butterfly within itself. Similarly, it is coherent to say that within a growth curve the principle of action is hidden.

Therefore, only if there is a metamorphosis will it be possible in both cases to emerge the real essence.

Thus, it is proposed through the PPFM spreadsheet to unleash the essence of the growth curve, bringing out the fullness of the action principle, by follow the numeric metamorphosis.



REFERENCES

- AHMADI, H.; MOTTAGHITALAB, M. Hyperbolic models as a new powerful tool to describe broiler growth kinetics. **Poultry science**, v. 86, n. 11, p. 2461-2465, 2007. <https://academic.oup.com/ps/article/86/11/2461/1573693>
- ALI, M. A. et al. Human growth in Japanese children: An application of triphasic generalized logistic model. **International Journal of Statistics**, v. 3, p. 75-92, 2004. http://www.ru.ac.bd/stat/wp-content/uploads/sites/25/2019/01/P7.Vol3_.pdf
- ANDERSON, Malcolm; HADI, Miftachul. Fermat's Principle and Hamilton's Principle: Does a least action take a least time for happening?. 2019. In: <https://osf.io/preprints/inarxiv/h5egu/download>
- ARCHONTOULIS, Sotirios V.; MIGUEZ, Fernando E. Nonlinear regression models and applications in agricultural research. **Agronomy Journal**, v. 107, n. 2, p. 786-798, 2015. <https://dl.sciencesocieties.org/publications/aj/pdfs/107/2/786>
- ARNDT, Markus; JUFFMANN, Thomas; VEDRAL, Vlatko. Quantum physics meets biology. **HFSP journal**, v. 3, n. 6, p. 386-400, 2009. <https://www.tandfonline.com/doi/pdf/10.2976/1.3244985>
- BARANYI, J.; ROBERTS, T. A.; MCCLURE, P. A non-autonomous differential equation to model bacterial growth. **Food microbiology**, v. 10, n. 1, p. 43-59, 1993. http://smas.chemeng.ntua.gr/miram/files/publ_79_13_1_2004.pdf
- BARANYI, József; ROBERTS, Terry A. A dynamic approach to predicting bacterial growth in food. **International journal of food microbiology**, v. 23, n. 3-4, p. 277-294, 1994. https://www.researchgate.net/profile/Jozsef_Baranyi/publication/15326559_A_Dynamic_Approach_to_Predicting_Bacterial_Growth_in_Food/links/5a1d2e02aca2726120b28eba/A-Dynamic-Approach-to-Predicting-Bacterial-Growth-in-Food.pdf
- BARANYI, József; ROBERTS, Terry A. Mathematics of predictive food microbiology. **International journal of food microbiology**, v. 26, n. 2, p. 199-218, 1995. <https://www.sciencedirect.com/science/article/pii/016816059400121L/pdf?md5=5ebd36b9eb16141b7d5c2df8fd16fa0c&pid=1-s2.0-016816059400121L-main.pdf>
- BATY, Florent; DELIGNETTE-MULLER, Marie-Laure. Estimating the bacterial lag time: which model, which precision?. **International journal of food microbiology**, v. 91, n. 3, p. 261-277, 2004. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.579.3533&rep=rep1&type=pdf>
- BEBBINGTON, M. et al. Dynamics and phases of kiwifruit (*Actinidia deliciosa*) growth curves. **New Zealand Journal of Crop and Horticultural Science**, v. 37, n. 3, p. 179-188, 2009. <https://www.tandfonline.com/doi/pdf/10.1080/01140670909510263>
- BEIKI, Hamid et al. Evaluation of growth functions on Japanese quail lines. **The Journal of Poultry Science**, v. 50, n. 1, p. 20-27, 2013. https://www.jstage.jst.go.jp/article/jpsa/50/1/50_0110142/_pdf
- BEJARANO, Adriana C.; WELLS, Randall S.; COSTA, Daniel P. Development of a bioenergetic model for estimating energy requirements and prey biomass consumption of the bottlenose dolphin *Tursiops truncatus*. **Ecological Modelling**, v. 356, p. 162-172, 2017. <http://costa.eeb.ucsc.edu/wp-content/uploads/2017/12/Bejarano-et-al.-2017-Development-of-a-bioenergetic-model-for-estimating-energy-requirements-and-prey-biomass-consumption-of-the-b.pdf>
- BEN-JACOB, Eshel. Learning from bacteria about natural information processing. **Annals of the New York Academy of Sciences**, v. 1178, n. 1, p. 78-90, 2009. <https://pdfs.semanticscholar.org/b307/84697ab45dcb157750f2acf9e677ea741cc.pdf>
- BENTEA, Lucian; WATZKY, Murielle A.; FINKE, Richard G. Sigmoidal nucleation and growth curves across nature fit by the Finke-Watzky model of slow continuous nucleation and autocatalytic growth: explicit formulas for the lag and growth times plus other key insights. **The Journal of Physical Chemistry C**, v. 121, n. 9, p. 5302-5312, 2017. <https://pubs.acs.org/doi/full/10.1021/acs.jpcc.6b12021>
- BIRCH, Colin PD. A new generalized logistic sigmoid growth equation compared with the Richards growth equation. **Annals of Botany**, v. 83, n. 6, p. 713-723, 1999. <https://academic.oup.com/aob/article-pdf/83/6/713/7983658/830713.pdf>
- BOCK, R. Darrell et al. A parameterization for individual human growth curves. **Human Biology**, p. 63-80, 1973. <https://www.jstor.org/stable/pdf/41459847.pdf>
- BOX, George EP. Robustness in the strategy of scientific model building. In: **Robustness in statistics**. Academic Press, 1979. p. 201-236. In: <https://www.sciencedirect.com/science/article/pii/B9780124381506500182>.
- BRIDSON, Eric Youlden; GOULD, G. W. Quantal microbiology. **Letters in Applied Microbiology**, v. 30, n. 2, p. 95-98, 2000. <https://onlinelibrary.wiley.com/doi/pdf/10.1046/j.1472-765x.2000.00673.x>
- BROOKES, Jennifer C. Quantum effects in biology: golden rule in enzymes, olfaction, photosynthesis and magnetodetection. **Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences**, v. 473, n. 2201, p. 20160822, 2017. <https://royalsocietypublishing.org/doi/pdf/10.1098/rspa.2016.0822>
- BROUGHALL, J. M.; BROWN, C. Hazard analysis applied to microbial growth in foods: development and application of three-dimensional models to predict bacterial growth. **Food Microbiology**, v. 1, n. 1, p. 13-22, 1984. <https://www.sciencedirect.com/science/article/pii/0740002084900054/pdf?md5=784486efc948dbde308611a83c968ea9&pid=1-s2.0-0740002084900054-main.pdf>
- BROWN, William P. et al. Are parametric models suitable for estimating avian growth rates?. **Journal of Avian Biology**, v. 38, n. 4, p. 495-506, 2007. <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.0908-8857.2007.03979.x>



BUCHANAN, Robert L.; CYGNAROWICZ, Miriam L. A mathematical approach toward defining and calculating the duration of the lag phase. **Food Microbiology**, v. 7, n. 3, p. 237-240, 1990. <https://www.sciencedirect.com/science/article/pii/074000209090029H/pdf?md5=87a2462a0dfa65f891cbbb8db2ba31a4&pid=1-s2.0-074000209090029H-main.pdf>

CAI, Junmeng et al. A new five-parameter logistic model for describing the evolution of energy consumption. **Energy Sources, Part B: Economics, Planning, and Policy**, v. 11, n. 2, p. 176-181, 2016. <https://www.tandfonline.com/doi/full/10.1080/15567249.2011.592902>

CAO, Liying et al. A New Flexible Sigmoidal Growth Model. **Symmetry**, v. 11, n. 2, p. 204, 2019. <https://www.mdpi.com/2073-8994/11/2/204/html>

CHA, Yuan; MURRAY, Christopher J.; KLINMAN, Judith P. Hydrogen tunneling in enzyme reactions. **Science**, v. 243, n. 4896, p. 1325-1330, 1989. <https://science.sciencemag.org/content/sci/243/4896/1325.full.pdf>

CHAKRABORTY, Biman; BHOWMICK, Amiya Ranjan; CHATTOPADHYAY, Joydev; BHATTACHARYA, Sabyasachi A Novel Unification Method to Characterize a Broad Class of Growth Curve Models Using Relative Growth Rate. **Bull Math Biol** 81: 2529, 2019. <https://doi.org/10.1007/s11538-019-00617-w>

CHANG, Y. C. Halley's comet: Tendencies in its orbital evolution and its ancient history. **Chinese astronomy**, v. 3, n. 1, p. 120-131, 1979. <https://www.sciencedirect.com/science/article/pii/0146636479900847/pdf?md5=9cb37135bf7557392ab93dd759ec9ed2&pid=1-s2.0-0146636479900847-main.pdf>

CHUNG, Sung Jang. On the Possible Deeper Structure of Leptons and Quarks: A View of the "Ultron"- "Logotron" Theory. **Open Journal of Philosophy**, v. 5, n. 05, p. 302, 2015. http://file.scirp.org/pdf/OJPP_2015052513404531.pdf

DALGAARD, Paw. Modelling of microbial activity and prediction of shelf life for packed fresh fish. **International Journal of Food Microbiology**, v. 26, n. 3, p. 305-317, 1995. <https://pdfs.semanticscholar.org/7718/cc33ac03527446b959800983421e8d9ddace.pdf>

DARMANI KUHI, H. et al. An evaluation of different growth functions for describing the profile of live weight with time (age) in meat and egg strains of chicken. **Poultry Science**, v. 82, n. 10, p. 1536-1543, 2003. <https://academic.oup.com/ps/article-pdf/82/10/1536/4468466/poultrysci82-1536.pdf>

DI CRESCENZO, Antonio; SPINA, Serena. Analysis of a growth model inspired by Gompertz and Korf laws, and an analogous birth-death process. **Mathematical biosciences**, v. 282, p. 121-134, 2016. <https://arxiv.org/pdf/1610.09297>

EBY, Wayne M.; TABATABAI, Mohammad A.; BURSAC, Zoran. Hyperbolic modeling of tumor growth with a combined treatment of iodoacetate and dimethylsulphoxide. **BMC cancer**, v. 10, n. 1, p. 509, 2010. <https://bmccancer.biomedcentral.com/articles/10.1186/1471-2407-10-509>

EL LOZY, Mohamed. A critical analysis of the double and triple logistic growth curves. **Annals of human biology**, v. 5, n. 4, p. 389-394, 1978. <https://www.tandfonline.com/doi/pdf/10.1080/03014467800003021>

FEYNMAN, R.; LEIGHTON, R.; SANDS, M. The Feynman Lectures on Physics (The Principle of Least Action). New Millennium Edition. California Institute of Technology.(Caltech), 2010. http://www.feynmanlectures.caltech.edu/II_19.html

FEYNMAN, Richard P. The principle of least action in quantum mechanics. In: **Feynman's Thesis—A New Approach To Quantum Theory**. 2005. p. 1-69. https://www.worldscientific.com/doi/abs/10.1142/9789812567635_0001 / <https://cds.cern.ch/record/101498/files/Thesis-1942-Feynman.pdf>

FISHER, Matthew PA. Quantum cognition: the possibility of processing with nuclear spins in the brain. **Annals of Physics**, v. 362, p. 593-602, 2015. <https://arxiv.org/pdf/1508.05929>

FLEMING, Graham R.; SCHOLLES, Gregory D.; CHENG, Yuan-Chung. Quantum effects in biology. **Procedia Chemistry**, v. 3, n. 1, p. 38-57, 2011. https://www.sciencedirect.com/science/article/pii/S1876619611000507/pdf?md5=8824b9b2a0d7e15219183399ada162ef&pid=1-s2.0-S1876619611000507-main.pdf&_valck=1

GARFIELD, Michael. The spooky world of quantum biology. **HPlus Magazine**, 2009. In: <https://hplusmagazine.com/2009/06/01/spooky-world-quantum-biology/>

GIBSON, Angela M.; BRATCHELL, N.; ROBERTS, T. A. Predicting microbial growth: growth responses of salmonellae in a laboratory medium as affected by pH, sodium chloride and storage temperature. **International journal of food microbiology**, v. 6, n. 2, p. 155-178, 1988. <https://www.sciencedirect.com/science/article/pii/0168160588900517/pdf?md5=917faf001d6306c978cb8620726fe0e9&pid=1-s2.0-0168160588900517-main.pdf>

GIBSON, Angela M.; BRATCHELL, N.; ROBERTS, T. A. The effect of sodium chloride and temperature on the rate and extent of growth of Clostridium botulinum type A in pasteurized pork slurry. **Journal of Applied Bacteriology**, v. 62, n. 6, p. 479-490, 1987. <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2672.1987.tb02680.x>

GIRTLE, Jerzy. Conception of valuation of combustion engine operation. **Journal of KONES**, v. 15, p. 89-96, 2008. http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BUJ8-0002-0008/c/httpwww_bg_utm_edu_plartjok22008jo20kones20200820n020220vol201520girtler.pdf

GIRTLE, Jerzy. Energetic aspect of diesel engine operation. **Silniki Spalinowe (Combustion Engines)**, n. 2, 2009a. https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-LOD9-0010-0008/c/httpwww_bg_utm_edu_plartsilniki20spalinowe2009ptnss-2009-ss2-202.pdf

GIRTLE, Jerzy. Possibility of valuation of operation of marine diesel engines. **Journal of Polish CIMAC**, v. 4, n. 1, p. 29-40, 2009b. http://www.polishcimeac.pl/files/all_4_1.pdf#page=29

GIRTLE, Jerzy. The method for determining the theoretical operation of ship diesel engines in terms of energy and assessment of the real operation of such engines, including indicators of their performance. **Journal of Polish CIMAC**, v. 6, n. 1, p. 79-88, 2011. <http://polishcimeac.pl/Papers1/2011/008.pdf>

GIRTLE, Jerzy; KUSZMIDER, S.; PLEWIŃSKI, L. Valuation method for operation of crankshaftpiston assembly in combustion engines in energy approach. **Journal of Polish CIMAC**, v. 6, n. 1, p. 89-98, 2011. <http://polishcimeac.pl/Papers1/2011/009.pdf>



GLEISS, Adrian C.; WILSON, Rory P.; SHEPARD, Emily LC. Making overall dynamic body acceleration work: on the theory of acceleration as a proxy for energy expenditure. **Methods in Ecology and Evolution**, v. 2, n. 1, p. 23-33, 2011. <https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/j.2041-210X.2010.00057.x>

GONGA, Zhi-hao; TANGA, Zhou-fei; CAO, Jian-shu; WUA, Jianlan. Optimal initialization of a quantum system for an efficient coherent energy transfer. **Chinese Journal of Chemical Physics** 31, 421, 2018. <https://doi.org/10.1063/1674-0068/31/cjcp1804068>

GOTTSCHALK, Paul G.; DUNN, John R. The five-parameter logistic: a characterization and comparison with the four-parameter logistic. **Analytical biochemistry**, v. 343, n. 1, p. 54-65, 2005. https://www.researchgate.net/profile/John_Dunn3/publication/7788394_The_five-parameter_logistic_A_characterization_and_comparison_with_the_four-parameter_logistic/links/5c82ab15299bf1268d48559a/The-five-parameter-logistic-A-characterization-and-comparison-with-the-four-parameter-logistic.pdf

GRANDPIERRE, A.; KAFATOS, M. Biological Autonomy. **Philosophy Study** 2 (9), pp. 631-649, 2012. In: <https://philarchive.org/archive/GRABA>

GRANDPIERRE, Attila et al. A multidisciplinary approach to mind and consciousness. **NeuroQuantology**, v. 11, n. 4, 2013. <http://www.neuroquantology.com/index.php/journal/article/viewFile/703/627>

GRANDPIERRE, Attila. Biological extension of the action principle: Endpoint determination beyond the quantum level and the ultimate physical roots of consciousness. **arXiv preprint arXiv:0802.0601**, 2008. <https://arxiv.org/pdf/0802.0601>

GRANDPIERRE, Attila. Biological Version of the Action Principle : The Next Frontier of Physics. Apeiron Centre. p. 1-20, 2009 In: <https://apeironcentre.org/biological-version-of-the-action-principle-the-next-frontier-of-physics/>

GRANDPIERRE, Attila. Biologically organized quantum vacuum and the cosmic origin of cellular life. In: **Phenomenology of Space and Time**. Springer, Cham, 2014. p. 107-133. <https://konkoly.hu/staff/grandpierre/Grandpierre2014BiologicallyOrganizedQuantumVacuum.pdf>

GRANDPIERRE, Attila. Fundamental complexity measures of life. **arXiv preprint arXiv:1204.6670**, 2011b. <https://arxiv.org/pdf/1204.6670>

GRANDPIERRE, Attila. Genuine Biological Autonomy: How can the Spooky Finger of Mind play on the Physical Keyboard of the Brain?. 2012. <https://philarchive.org/archive/ATTGBA>

GRANDPIERRE, Attila. On the biological origin of design in Nature. In: **Origin (s) of Design in Nature**. Springer, Dordrecht, 2012. p. 17-41. https://link.springer.com/chapter/10.1007/978-94-007-4156-0_2

GRANDPIERRE, Attila. On the first principle of biology and the foundation of the universal science. In: **Astronomy and Civilization in the New Enlightenment**. Springer, Dordrecht, 2011a. p. 19-36. https://www.researchgate.net/profile/Attila_Grandpierre/publication/227182727_On_the_First_Principle_of_Biology_and_the_Foundation_of_the_Universal_Science/inks/0912f50dc9fe05d0ac000000.pdf

GRANDPIERRE, Attila. The Biological Principle of Natural Sciences and the Logos of Life of Natural Philosophy: a Comparison and the Perspectives of Unifying the Science and Philosophy of Life. In: **Phenomenology/Ontopoiesis Retrieving Geo-cosmic Horizons of Antiquity**. Springer, Dordrecht, 2011c. p. 711-727. <https://philpapers.org/archive/GRATBP>

GRANDPIERRE, Attila. The Fundamental Biological Activity of the Universe. In: **Eco-Phenomenology: Life, Human Life, Post-Human Life in the Harmony of the Cosmos**. Springer, Cham, 2018. p. 115-140. <http://www.grandpierre.hu/site/wp-content/uploads/2018/10/Grandpierre-2018-The-Fundamental-Biological-Activity-of-the-Universe.pdf>

GRANDPIERRE, Attila. The Fundamental Principles of Existence and the Origin of Physical Laws. **Ultimate Reality and Meaning**, v. 25, n. 2, p. 127-147, 2002. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.859.4273&rep=rep1&type=pdf>

GRANDPIERRE, Attila; CHOPRA, Deepak; KAFATOS, Menas C. The universal principle of biology: determinism, quantum physics and spontaneity. **NeuroQuantology**, v. 12, n. 3, 2014. <https://www.neuroquantology.com/index.php/journal/article/viewFile/747/667>

GRANDPIERRE, Attila; KAFATOS, Menas. Genuine Biological Autonomy: How can the Spooky Finger of Mind Play on the Physical Keyboard of the Brain. **An Anthology of Philosophical Studies**, v. 7, p. 83-98, 2013. <https://www.konkoly.hu/staff/grandpierre/Genuine.pdf>

HEINEN, M. Analytical growth equations and their Genstat 5 equivalents. **NJAS wageningen journal of life sciences**, v. 47, n. 1, p. 67-89, 1999. <https://library.wur.nl/ojs/index.php/njas/article/download/479/195/>

HERNANDEZ-LLAMAS, Alfredo; RATKOWSKY, David A. Growth of fishes, crustaceans and molluscs: estimation of the von Bertalanffy, Logistic, Gompertz and Richards curves and a new growth model. **Marine Ecology Progress Series**, v. 282, p. 237-244, 2004. <https://www.int-res.com/articles/meps2004/282/m282p237.pdf>

ISHIZAKI, Akihito; FLEMING, Graham R. Quantum superpositions in photosynthetic light harvesting: delocalization and entanglement. **New Journal of Physics**, v. 12, n. 5, p. 055004, 2010. <https://iopscience.iop.org/article/10.1088/1367-2630/12/5/055004/pdf>

JABR, Ferris. How brainless slime molds redefine intelligence. **Scientific American**, v. 7, 2012. <https://www.scientificamerican.com/article/brainless-slime-molds/>

JACOB, Eshel Ben et al. Bacterial linguistic communication and social intelligence. **TRENDS in Microbiology**, v. 12, n. 8, p. 366-372, 2004. http://www.israela-becker.me/docs/ben-jacob_becker_shapira_levine_2004.pdf

Ji, Li Qun; FANG, Dan Dan. New asymmetric five-parameter logistic model for forecasting petroleum consumption in China. In: **Applied Mechanics and Materials**. **Trans Tech Publications**, 2015. p. 483-488. <https://www.scientific.net/AMM.738-739.483.pdf>



- JOHNSON, Lionel. An ecological approach to biosystem thermodynamics. **Biology and Philosophy**, v. 7, n. 1, p. 35-60, 1992. <https://link.springer.com/content/pdf/10.1007/BF00130163.pdf>
- JOHNSON, Lionel. Macroecology: The organizing forces. **Biotechnology progress**, v. 22, n. 1, p. 156-166, 2006. <https://onlinelibrary.wiley.com/doi/pdf/10.1021/bp0580039>
- JONES, Julie E.; WALKER, Steven J. Advances in modeling microbial growth. *Journal of Industrial Microbiology*, v. 12, n. 3-5, p. 200-205, 1993. <https://link.springer.com/content/pdf/10.1007/BF01584191.pdf>
- KAPLAN, Selçuk; GÜRCAN, Eser Kemal. Comparison of growth curves using non-linear regression function in Japanese quail. **Journal of Applied Animal Research**, v. 46, n. 1, p. 112-117, 2018. <https://www.tandfonline.com/doi/full/10.1080/09712119.2016.1268965?af=R>
- KOOPS, W. J. Multiphasic growth curve analysis. **Growth**, v. 50, n. 2, p. 169-177, 1986. In: <http://edepot.wur.nl/206151#page=18>
- KOUTSOUMANIS, Konstantinos. Predictive modeling of the shelf life of fish under nonisothermal conditions. **Appl. Environ. Microbiol.**, v. 67, n. 4, p. 1821-1829, 2001. <https://aem.asm.org/content/aem/67/4/1821.full.pdf>
- KOYA, Purnachandra Rao; GOSHU, Ayele Taye. Generalized mathematical model for biological growths. **Open Journal of Modelling and Simulation**, v. 1, n. 04, p. 42, 2013. <https://pdfs.semanticscholar.org/3c4a/495c480e268ada4d3fc68ec0d9c58a378859.pdf>
- KYURKCHIEV, N.; ILIEV, A. On some growth curve modeling: approximation theory and applications. **Int. J. of Trends in Research and Development**, v. 3, n. 3, p. 466-471, 2016. https://www.researchgate.net/publication/304489806_On_Some_Growth_Curve_Modeling_Approximation_Theory_and_Applications
- LAMBERT, Neill et al. Quantum biology. **Nature Physics**, v. 9, n. 1, p. 10-18, 2013. https://www.researchgate.net/profile/Franco_Nori/publication/233923372_Quantum_biology/links/0deec53c9030171813000000/Quantum-biology.pdf
- LAMBERTINI, E. et al. New mathematical approaches to quantify human infectious viruses from environmental media using integrated cell culture-qPCR. **Journal of virological methods**, v. 163, n. 2, p. 244-252, 2010. <http://www.suzuki-labo.com/img/member/magazine123.pdf>
- LEGAN, David et al. Modelling the growth, survival and death of bacterial pathogens in foods. **Foodborne pathogens: hazards, risk and control**. Woodhead Publishing, Cambridge, United Kingdom, p. 53-95, 2002. In: http://www.aua.gr/skandamis/Literature/Enotita_3/Foodborne_Pathogens.pdf#page=68
- LEHMAN, Brendan; PERSINGER, Michael A. Convergent quantification and physical support for Teilhard de Chardin's philosophy concerning the human species and evolutionary consciousness. **Open Journal of Philosophy**, v. 5, n. 06, p. 338, 2015. https://www.researchgate.net/profile/Brendan_Lehman/publication/280647948_Convergent_Quantification_and_Physical_Support_for_Teilhard_de_Chardin%27s_Philosophy_Concerning_the_Human_Species_and_Evolutionary_Consciousness/links/55c0c2be08ae9289a09ba373/Convergent-Quantification-and-Physical-Support-for-Teilhard-de-Chardins-Philosophy-Concerning-the-Human-Species-and-Evolutionary-Consciousness.pdf
- LENGAUER, Thomas. Computational biology at the beginning of the post-genomic era. In: **Informatics**. Springer, Berlin, Heidelberg, 2001. p. 341-355. <https://link.springer.com/content/pdf/10.1007%2F3-540-44577-3.pdf>
- LÓPEZ, Sophie et al. Statistical evaluation of mathematical models for microbial growth. **International journal of food microbiology**, v. 96, n. 3, p. 289-300, 2004. <https://www.sciencedirect.com/science/article/pii/S0168160504002041/pdf?md5=93d9d2c39e95d8d899d4a39f8ce5c462&pid=1-s2.0-S0168160504002041-main.pdf>
- MARAIS, Adriana et al. The future of quantum biology. **Journal of the Royal Society Interface**, v. 15, n. 148, p. 20180640, 2018. <https://royalsocietypublishing.org/doi/pdf/10.1098/rsif.2018.0640>
- MARLETTO, C. et al. Entanglement between living bacteria and quantized light witnessed by Rabi splitting. **Journal of Physics Communications**, v. 2, n. 10, p. 101001, 2018. <https://iopscience.iop.org/article/10.1088/2399-6528/aae224/pdf>
- MARTINÁS, Katalin. Principle of Greatest Happiness. In: **Astronomy and Civilization in the New Enlightenment**. Springer, Dordrecht, 2011. p. 277-282. https://link.springer.com/chapter/10.1007/978-90-481-9748-4_28
- MARUŠIĆ, M. et al. Analysis of growth of multicellular tumour spheroids by mathematical models. **Cell proliferation**, v. 27, n. 2, p. 73-94, 1994. <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2184.1994.tb01407.x>
- MATHEW, Santhosh. The Spooky World of Quantum Entanglement. In: **Essays on the Frontiers of Modern Astrophysics and Cosmology**. Springer, Cham, 2014. p. 149-162. <https://link.springer.com/content/pdf/10.1007%2F978-3-319-01887-4.pdf>
- MAYNE, Richard; ADAMATZKY, Andrew; JONES, Jeff. On the role of the plasmodial cytoskeleton in facilitating intelligent behavior in slime mold *Physarum polycephalum*. **Communicative & integrative biology**, v. 8, n. 4, p. e1059007, 2015. <https://www.tandfonline.com/doi/full/10.1080/19420889.2015.1059007>
- MCCLURE, P. J. et al. Modelling the growth, survival and death of microorganisms in foods: the UK Food Micromodel approach. **International journal of food microbiology**, v. 23, n. 3-4, p. 265-275, 1994. <https://www.sciencedirect.com/science/article/pii/S0168160594901562/pdf?md5=7b273fd9fe1edffedf8c847d43a369a4&pid=1-s2.0-0168160594901562-main.pdf>
- MCCLURE, P. J.; COLE, M. B.; DAVIES, K. W. An example of the stages in the development of a predictive mathematical model for microbial growth: the effects of NaCl, pH and temperature on the growth of *Aeromonas hydrophila*. **International journal of food microbiology**, v. 23, n. 3-4, p. 359-375, 1994. <https://www.sciencedirect.com/science/article/pii/S0168160594901635/pdf?md5=260cc093c9842c8b8a31a0b435f0fdc1&pid=1-s2.0-0168160594901635-main.pdf>
- MCFEE, Wayne E. et al. Investigation of growth phases for bottlenose dolphins using a Bayesian modeling approach. **Marine Mammal Science**, v. 26, n. 1, p. 67-85, 2010. <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1748-7692.2009.00306.x>
- MEMBRÉ, J. M.; THURETTE, J.; CATTEAU, M. Modelling the growth, survival and death of *Listeria monocytogenes*. **Journal of Applied Microbiology**, v. 82, n. 3, p. 345-350, 1997. <https://onlinelibrary.wiley.com/doi/pdf/10.1046/j.1365-2672.1997.00367.x>



- MIE, Halmi. Evaluation of Several Mathematical Models for Fitting the Growth and Kinetics of the Catechol-degrading *Candida parapsilopsis*: Part 1. **Journal of Environmental Bioremediation and Toxicology**, v. 2, n. 2, p. 48-52, 2014. <https://pdfs.semanticscholar.org/4efc/b637c8a17a99f5cd29b123bc95b28d59cdc7.pdf>
- MOATE, Peter J. et al. A modified logistic model to describe gadolinium kinetics in breast tumors. **Magnetic resonance imaging**, v. 22, n. 4, p. 467-473, 2004. <http://keszei.chem.elte.hu/common/ModLogModel.pdf>
- MOORE, Thomas A. Getting the most action out of least action: A proposal. **American Journal of Physics**, v. 72, n. 4, p. 522-527, 2004. http://www.eftaylor.com/pub/moore_action.html
- NAGAO, Keiichi; NIELSEN, Holger Bech. Complex action suggests future-included theory. **Progress of Theoretical and Experimental Physics**, v. 2017, n. 11, p. 111B01, 2017. <https://academic.oup.com/ptep/article/2017/11/111B01/4653784>
- NARUSHIN, V. G.; TAKMA, C. Sigmoid model for the evaluation of growth and production curves in laying hens. **Biosystems engineering**, v. 84, n. 3, p. 343-348, 2003. <http://norsemathology.org/wiki/images/3/38/Sdarticle.pdf>
- NEALE, Lex. Integral Relativity-New Cosmological Paradigm for Science of Consciousness Protocols. **NeuroQuantology**, v. 17, n. 5, 2019. <http://www.neuroquantology.com/index.php/journal/article/download/2389/1381>
- NEMESTÓTHY, Nándor et al. Assessment via the modified gompertz-model reveals new insights concerning the effects of ionic liquids on biohydrogen production. **International Journal of Hydrogen Energy**, v. 43, n. 41, p. 18918-18924, 2018. <https://www.sciencedirect.com/science/article/pii/S0360319918327496/pdf?md5=b49bec7ed142951c3faf796ca4dad66e&pid=1-s2.0-S0360319918327496-main.pdf>
- OFFORD, Catherine. Quantum Biology May Help Solve Some of Life's Greatest Mysteries. *TheScientist*. p. 1-13, 2019. In: <https://www.the-scientist.com/features/quantum-biology-may-help-solve-some-of-lifes-greatest-mysteries-65873>
- OGBORN, Jon; HANC, Jozef; TAYLOR, Edwin F. Action on stage: Historical introduction. In: **The Girep conference**. 2006. <http://mail.eftaylor.com/pub/ActionSummary.pdf>
- OLIVEIRA, Agamenon RE. History of Two Fundamental Principles of Physics: Least Action and Conservation of Energy. **Advances in Historical Studies**, v. 3, n. 02, p. 83, 2014. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.824.8596&rep=rep1&type=pdf>
- OWEN-SMITH, Norman. Incorporating fundamental laws of biology and physics into population ecology: the metaphysiological approach. **Oikos**, v. 111, n. 3, p. 611-615, 2005. <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1600-0706.2005.14603.x>
- PANIK, M. J. (2013). PARAMETRIC GROWTH CURVE MODELING. In *Growth Curve Modeling*, M. J. Panik (Ed.). <https://onlinelibrary.wiley.com/doi/pdf/10.1002/9781118763971.ch3>
- PANITCHAYANGKOON, Gitt et al. Long-lived quantum coherence in photosynthetic complexes at physiological temperature. **Proceedings of the National Academy of Sciences**, v. 107, n. 29, p. 12766-12770, 2010. <https://www.pnas.org/content/pnas/107/29/12766.full.pdf>
- REED, Robert B.; BERKEY, Catherine S. Linear statistical model for growth in stature from birth to maturity. **American Journal of Human Biology**, v. 1, n. 3, p. 257-262, 1989. <https://onlinelibrary.wiley.com/doi/pdf/10.1002/ajhb.1310010305>
- RIBEIRO, Fabiano L. An attempt to unify some population growth models from first principles. **Revista Brasileira de Ensino de Física**, v. 39, n. 1, 2017. http://www.scielo.br/scielo.php?pid=S1806-11172017000100411&script=sci_arttext
- ROSEN, Marc A.; DINCER, Ibrahim; KANOGLU, Mehmet. Role of exergy in increasing efficiency and sustainability and reducing environmental impact. **Energy policy**, v. 36, n. 1, p. 128-137, 2008. <https://www.sciencedirect.com/science/article/pii/S0301421507003886/pdf?md5=a9e3beca508600584180669aaa350e00&pid=1-s2.0-S0301421507003886-main.pdf>
- ROSEN, Robert. Optimality in biology and medicine. **Journal of mathematical analysis and applications**, v. 119, n. 1-2, p. 203-222, 1986. https://www.sciencedirect.com/science/article/pii/0022247X86901538/pdf?md5=0632a9aa6c3549cea17e00480e515cee&pid=1-s2.0-0022247X86901538-main.pdf&_valck=1
- RUDNICKI, Jacek. On making operational decisions with taking into account value of operation applied to ship main propulsion engine as an example. **Journal of Polish CIMAC**, v. 4, n. 1, p. 145-153, 2009. <http://www.polishcimeac.pl/Papers1/2009/019.pdf>
- SCHWARTZ, Stephan A. Crossing the threshold: nonlocal consciousness and the burden of proof. **EXPLORE: The Journal of Science and Healing**, v. 9, n. 2, p. 77-81, 2013. <http://www.skepticalaboutskeptics.org/wp-content/uploads/2014/09/crossing-the-threshold-nonlocal-consciousness-and-the-burden-of-proof-stephan-a-schwartz.pdf>
- SHAHIN, Abu Md; ALI, Ayub Md; ALI, Shawkat ABM. An Extension of Generalized Triphasic Logistic Human Growth Model. **J Biomet Biostat** 4:162., 2013 <https://www.omicsonline.org/pdfdownload.php?download=open-access-pdfs-outside/an-extension-of-generalized-triphasic-logistic-human-growth-model-2155-6180.1000162.pdf&aid=12108>
- STRATHE, Anders Bjerring et al. A multilevel nonlinear mixed-effects approach to model growth in pigs. **Journal of Animal Science**, v. 88, n. 2, p. 638-649, 2010. <https://academic.oup.com/jas/article/88/2/638/4740605>
- SUTHERLAND, William J. The best solution. **Nature**, v. 435, n. 7042, p. 569, 2005. <https://www.nature.com/articles/435569a.pdf>
- SWINNEN, I. A. M. et al. Predictive modelling of the microbial lag phase: a review. **International journal of food microbiology**, v. 94, n. 2, p. 137-159, 2004. <https://www.sciencedirect.com/science/article/pii/S0168160504000698/pdf?md5=1760ec163c593d79965aae1c3113ec99&pid=1-s2.0-S0168160504000698-main.pdf>
- SZPARAGA, Agnieszka; CZERWIŃSKA, Ewa. Modelling of beetroot seedlings with modified generalized logistic functions. **Agricultural Engineering**, v. 21, n. 3, p. 107-117, 2017. <https://www.degruyter.com/downloadpdf/j/agriceng.2017.21.issue-3/agriceng-2017-0030/agriceng-2017-0030.xml>



- SZPARAGA, Agnieszka; KOCIRA, Sławomir. Generalized logistic functions in modelling emergence of *Brassica napus* L. **PloS one**, v. 13, n. 8, p. e0201980, 2018. <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0201980>
- TABATABAI, Mohammad A. et al. A flexible multivariable model for phytoplankton growth. **Mathematical biosciences and engineering: MBE**, v. 10, n. 3, p. 913-923, 2013a. <https://doi.org/10.3934/mbe.2013.10.913>
- TABATABAI, Mohammad A. et al. T model of growth and its application in systems of tumor-immune dynamics. **Mathematical biosciences and engineering: MBE**, v. 10, n. 3, p. 925, 2013b. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4476034/>
- TABATABAI, Mohammad; WILLIAMS, David Keith; BURSAC, Zoran. Hyperbolic growth models: theory and application. **Theoretical Biology and Medical Modelling**, v. 2, n. 1, p. 14, 2005. <https://tbiomed.biomedcentral.com/articles/10.1186/1742-4682-2-14>
- TAOUKIS, P. S.; KOUTSOUMANIS, K.; NYCHAS, G. J. E. Use of time-temperature integrators and predictive modelling for shelf life control of chilled fish under dynamic storage conditions. **International journal of food microbiology**, v. 53, n. 1, p. 21-31, 1999. http://smas.chemeng.ntua.gr/files/pubs/TTI_chilledfish.pdf
- TELEKEN, Jhony Tiago; GALVÃO, Alessandro Cazonatto; ROBAZZA, Weber da Silva. Use of modified Richards model to predict isothermal and non-isothermal microbial growth. **Brazilian journal of microbiology**, v. 49, n. 3, p. 614-620, 2018. http://www.scielo.br/scielo.php?pid=S1517-83822018000300614&script=sci_arttext
- TELEKEN, Jhony Tiago; ROBAZZA, Weber da Silva; GOMES, Gilmar de Almeida. Mathematical modeling of microbial growth in milk. **Food Science and Technology**, v. 31, n. 4, p. 891-896, 2011. http://www.scielo.br/scielo.php?pid=S0101-20612011000400010&script=sci_arttext
- THEISE, Neil D.; KAFATOS, Menas. Sentience everywhere: complexity theory, panpsychism & the role of sentience in self-organization of the universe. **Journal of Consciousness Exploration & Research**, v. 4, n. 4, 2013. <https://jcer.com/index.php/jcj/article/download/291/330>
- TJØRVE, Even; TJØRVE, Kathleen MC. A unified approach to the Richards-model family for use in growth analyses: why we need only two model forms. **Journal of theoretical biology**, v. 267, n. 3, p. 417-425, 2010. <https://www.sciencedirect.com/science/article/pii/S0022519310004741/pdf?md5=245f03310b8c5ebac947ada06ee58724&pid=1-s2.0-S0022519310004741-main.pdf>
- TJØRVE, Kathleen MC; TJØRVE, Even. The use of Gompertz models in growth analyses, and new Gompertz-model approach: An addition to the Unified-Richards family. **PloS one**, v. 12, n. 6, p. e0178691, 2017. <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0178691>
- TOMLINSON, Sean et al. Applications and implications of ecological energetics. **Trends in ecology & evolution**, v. 29, n. 5, p. 280-290, 2014. https://www.researchgate.net/profile/Don_Bradshaw/publication/261606935_Applications_and_implications_of_ecological_energetics/links/59f94ac9458515547c26b870/Applications-and-implications-of-ecological-energetics.pdf
- TSOULARIS, Anastasios; WALLACE, James. Analysis of logistic growth models. **Mathematical biosciences**, v. 179, n. 1, p. 21-55, 2002. https://mro.massey.ac.nz/bitstream/handle/10179/4341/Analysis_of_Logistic_Growth_Models.pdf?sequence=1&isAllowed=y
- VON BERTALANFFY, Ludwig. Problems of life; an evaluation of modern biological thought. 1952.
- VRÁNA, Jakub et al. Choosing the right sigmoid growth function using the unified-models approach. **Ibis**, v. 161, n. 1, p. 13-26, 2019. <https://onlinelibrary.wiley.com/doi/pdf/10.1111/ibi.12592>
- WAN, Xinrong et al. A new four-parameter, generalized logistic equation and its applications to mammalian somatic growth. **Acta Theriologica**, v. 45, n. 2, p. 145-154, 2000. http://rcin.org.pl/ibs/Content/13000/BI002_2613_Cz-40-2_Acta-T44-nr16-145-153_o.pdf
- WEST, Geoffrey B.; BROWN, J. H.; ENQUIST, Brian J. Growth models based on first principles or phenomenology?. **Functional Ecology**, v. 18, n. 2, p. 188-196, 2004. <https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/j.0269-8463.2004.00857.x>
- WEST, Geoffrey B.; BROWN, James H.; ENQUIST, Brian J. A general model for ontogenetic growth. **Nature**, v. 413, n. 6856, p. 628, 2001. <https://pdfs.semanticscholar.org/2cf6/69a68a870bce2017498235e1094615d731f1.pdf>
- WESTERHOFF, Hans V. et al. Systems biology: the elements and principles of life. **FEBS letters**, v. 583, n. 24, p. 3882-3890, 2009. <https://www.sciencedirect.com/science/article/pii/S0014579309009119>
- WILSON, Rory P. et al. Moving towards acceleration for estimates of activity-specific metabolic rate in free-living animals: the case of the cormorant. **Journal of Animal Ecology**, v. 75, n. 5, p. 1081-1090, 2006. <https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2656.2006.01127.x%4010.1111/%28ISSN%291365-2656.BIOTEL>
- WINDARTO, Windarto; ERIDANI, Eridani; PURWATI, Utami Dyah. A new modified logistic growth model for empirical use. **Communication in Biomathematical Sciences**, v. 1, n. 2, p. 122-131, 2018. <http://journals.itb.ac.id/index.php/cbms/article/download/7717/3804>
- WIT, Ernst; HEUVEL, Edwin van den; ROMELJN, Jan-Willem. 'All models are wrong...': an introduction to model uncertainty. **Statistica Neerlandica**, v. 66, n. 3, p. 217-236, 2012. In: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1467-9574.2012.00530.x>.
- WOLYNES, Peter G. Some quantum weirdness in physiology. **Proceedings of the National Academy of Sciences** 106.41: 17247-17248, 2009. <https://www.pnas.org/content/106/41/17247.full>
- WU, Jianlan, Fan Liu, MA, Jian; SILBEY, Robert J.; CAO, Jianshu. Efficient energy transfer in light-harvesting systems: Quantum-classical comparison, flux network, and robustness analysis. **J. Chem. Phys.** 137, 174111, 2012. <https://doi.org/10.1063/1.4762839>
- YANG, Richard C.; KOZAK, Antel; SMITH, J. Harry G. The potential of Weibull-type functions as flexible growth curves. **Canadian Journal of Forest Research**, v. 8, n. 4, p. 424-431, 1978. <https://www.nrcresearchpress.com/doi/pdf/10.1139/x78-062>



ZEE, Anthony. **Fearful symmetry: The search for beauty in modern physics**. Princeton University Press, 2015.

ZEIDE, Boris. Analysis of growth equations. **Forest science**, v. 39, n. 3, p. 594-616, 1993. <http://www.isa.ulisboa.pt/cef/public/SAFMOD/textos/Papers/BorisZeideOriginal.pdf>

ZENG, Yan; WAN, Xinrong. A new mathematical model and its application to the growth of crustaceans. **CRUSTACEANA-INTERNATIONAL JOURNAL OF CRUSTACEAN RESEARCH**-, v. 73, n. 5, p. 565-574, 2000. <https://www.jstor.org/stable/pdf/20106319.pdf>

ZHA, Xiaoming et al. Dynamic Aggregation Modeling of Grid-Connected Inverters Using Hamilton's-Action-Based Coherent Equivalence. **IEEE Transactions on Industrial Electronics**, v. 66, n. 8, p. 6437-6448, 2019. <https://ieeexplore.ieee.org/iel7/41/4387790/08611250.pdf>

ZHANG, Yiteng et al. Delocalized quantum states enhance photocell efficiency. **Physical chemistry chemical physics**, v. 17, n. 8, p. 5743-5750, 2015. <https://link.aps.org/pdf/10.1103/PhysRevLett.111.253601>

ZHAO, Tian; HUA, Yu-Chao; GUO, Zeng-Yuan. The principle of least action for reversible thermodynamic processes and cycles. **Entropy**, v. 20, n. 7, p. 542, 2018. <https://www.mdpi.com/1099-4300/20/7/542/pdf>

ZULLINGER, Elissa M. et al. Fitting sigmoidal equations to mammalian growth curves. **Journal of Mammalogy**, v. 65, n. 4, p. 607-636, 1984. <https://www.jstor.org/stable/pdf/1380844.pdf>

ZWIETERING, M. H. et al. Modeling of the bacterial growth curve. **Appl. Environ. Microbiol.**, v. 56, n. 6, p. 1875-1881, 1990. <https://aem.asm.org/content/56/6/1875.full.pdf>

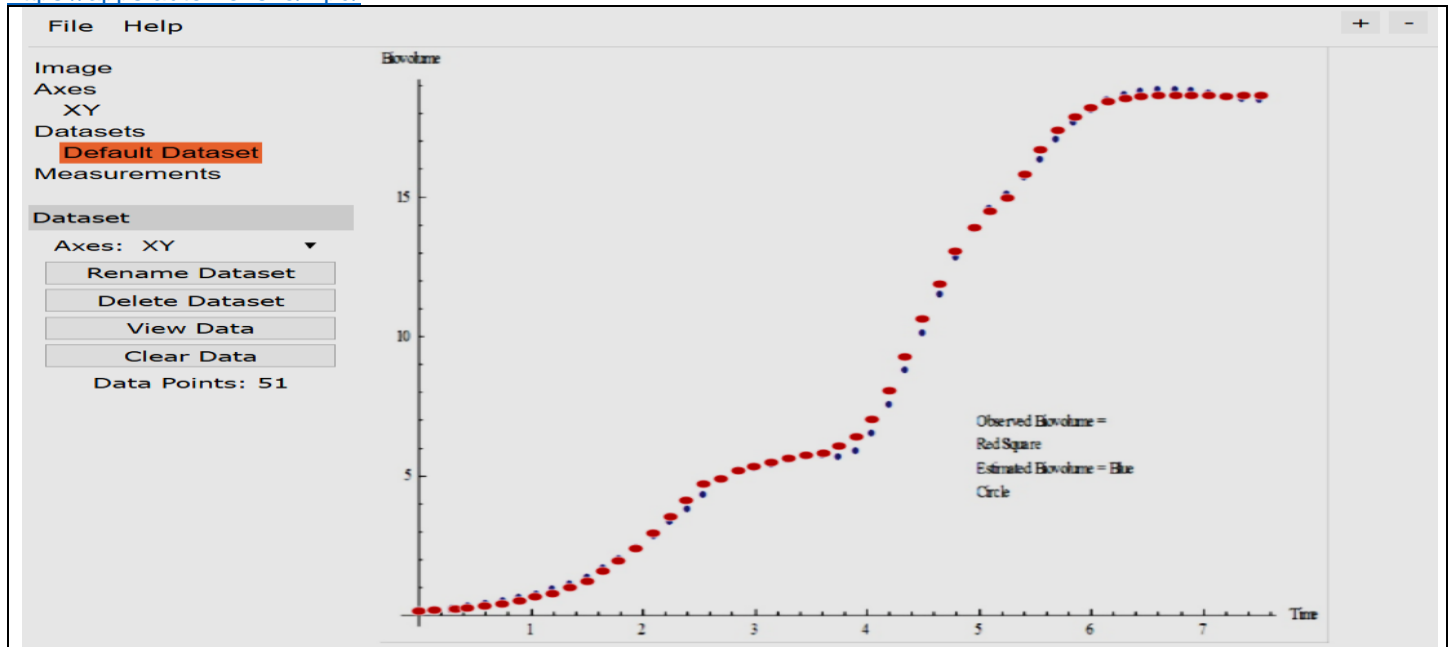


Appendix: examples of Curves Adjusted by PPFM spreadsheet

“A FLEXIBLE MULTIVARIABLE MODEL FOR PHYTOPLANKTON GROWTH”

https://www.aimspress.com/fileOther/PDF/MBE/1551-0018_2013_3_913.pdf

<https://apps.automeris.io/wpd/>





Fitting the Triple Logistic Model to Response Data **AIC_c = -221,64** **BIC = -207,819**

Clear Data Range HOME

Sample Statistics

Min Input	0,0000	Min Output	0,15
Max Input	7,4601	Max Output	18,69

Save

Menu

Point	Input (x)	Output (y)	Residuals	Expected	Qm
1	0	0,14742	0,0963	0,05115	0,1812
2	0,1373808	0,184275	0,1141	0,07014	0,1858
3	0,3265278	0,22113	0,1130	0,10809	0,1182
4	0,4296796	0,257985	0,1213	0,13666	0,1077
5	0,5843863	0,331695	0,1379	0,19377	0,0982
6	0,7390929	0,405405	0,1318	0,27363	0,0639
7	0,8937573	0,515971	0,1318	0,38415	0,0452
8	1,0311804	0,663391	0,1475	0,51593	0,0421
9	1,1858448	0,773956	0,0620	0,712	0,0054
10	1,3403824	0,995086	0,0261	0,96899	0,0007
11	1,49492	1,216216	-0,0795	1,29569	0,0049
12	1,6320895	1,584767	-0,0617	1,64651	0,0023
13	1,7692591	1,953317	-0,0970	2,05028	0,0046
14	1,9235432	2,395577	-0,1573	2,5529	0,0097
15	2,0777004	2,948403	-0,1320	3,08041	0,0057
16	2,2318155	3,538084	-0,0624	3,60052	0,0011
17	2,3687315	4,127764	0,0962	4,03154	0,0023
18	2,5228465	4,717445	0,2563	4,4611	0,0147
19	2,6774264	4,90172	0,0798	4,82192	0,0013
20	2,8318795	5,19656	0,0846	5,11197	0,0014
21	2,9693026	5,34398	0,0268	5,31715	0,0001
22	3,1239247	5,4914	-0,0091	5,50045	1E-05
23	3,2785468	5,638821	-0,0111	5,64988	2E-05
24	3,4332112	5,749386	-0,0384	5,78774	0,0003
25	3,5879178	5,823096	-0,1234	5,94649	0,0026
26	3,7252142	6,081081	-0,0653	6,14635	0,0007
27	3,879625	6,412776	-0,0997	6,51248	0,0015
28	4,0164987	7,039312	-0,0139	7,05318	3E-05
29	4,1701067	8,071253	0,0617	8,00959	0,0005
30	4,3063043	9,287469	0,1060	9,18148	0,0012
31	4,4595319	10,65111	-0,0375	10,6886	0,0001
32	4,6128863	11,90418	-0,1717	12,0759	0,0024
33	4,7491262	13,08354	0,0526	13,0309	0,0002
34	4,9201444	13,9312	0,0410	13,8902	0,0001
35	5,0570604	14,52088	0,0723	14,4485	0,0004
36	5,2113022	15	-0,1074	15,1074	0,0008
37	5,3651214	15,84767	-0,0372	15,8848	9E-05
38	5,5016994	16,73219	0,0981	16,6341	0,0006
39	5,6556876	17,43243	0,0349	17,3975	7E-05
40	5,8099294	17,91155	-0,0441	17,9556	0,0001
41	5,9471412	18,24324	-0,0266	18,2699	4E-05
42	6,1016789	18,46437	-0,0084	18,4728	4E-06
43	6,2563432	18,57494	-0,0033	18,5782	6E-07
44	6,3938509	18,64865	0,0219	18,6268	3E-05
45	6,5485998	18,6855	0,0306	18,6549	5E-05
46	6,7033909	18,6855	0,0169	18,6686	2E-05
47	6,840983	18,6855	0,0107	18,6748	6E-06
48	6,9957742	18,6855	0,0072	18,6783	3E-06
49	7,1506076	18,64865	-0,0313	18,68	5E-05
50	7,3053565	18,6855	0,0047	18,6808	1E-06
51	7,4601477	18,6855	0,0043	18,6812	1E-06

Regression

a	b	k	a'	b'	k'	a''	b''	k''	SSE
5,92605054	2,04359399	2,321240387	14,225899	4,3982294	4,70262581	24,6076167	5,45799002	4,70583568	0,4009

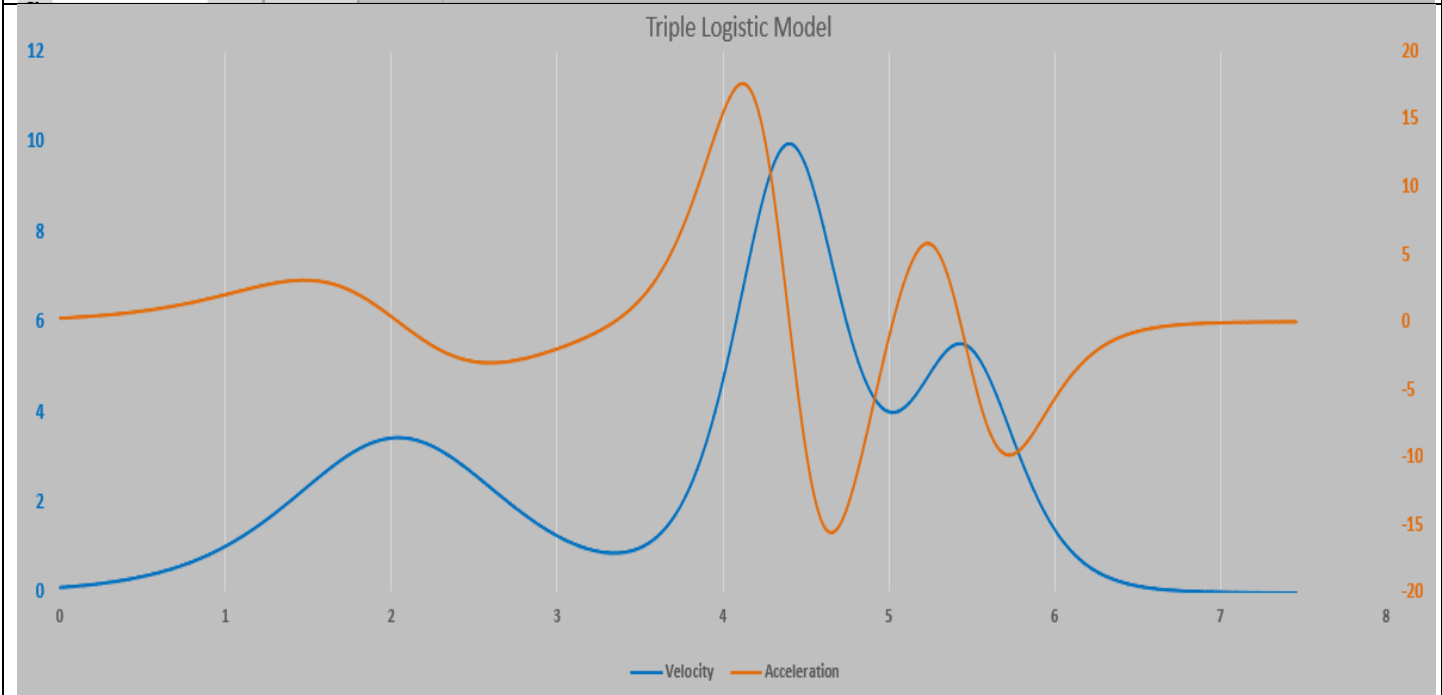
Goodness of Fit (R²_{adj}) 99,9843% **Qm = 0,907920533700217** **critical X² = 56,94238715**

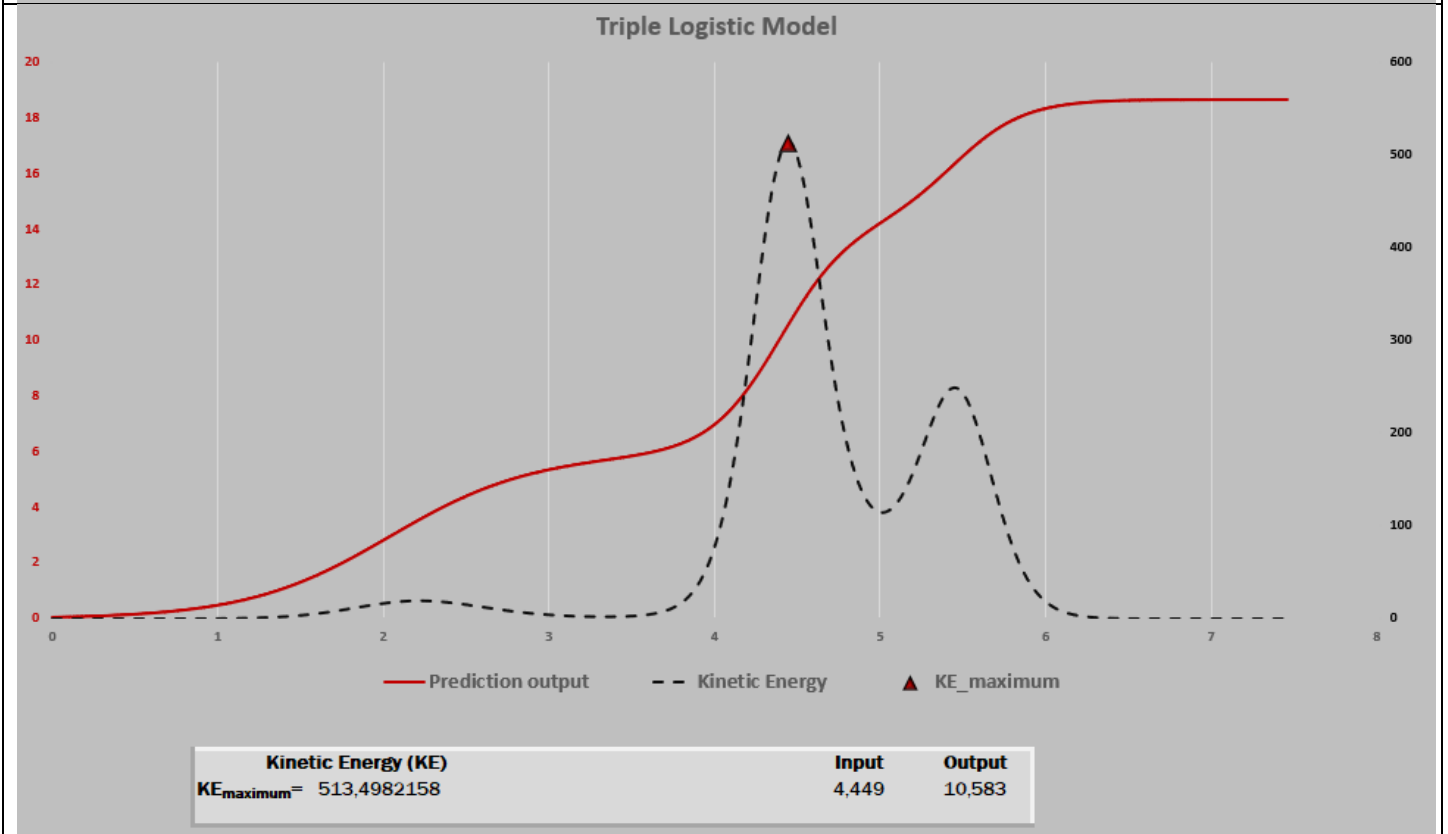
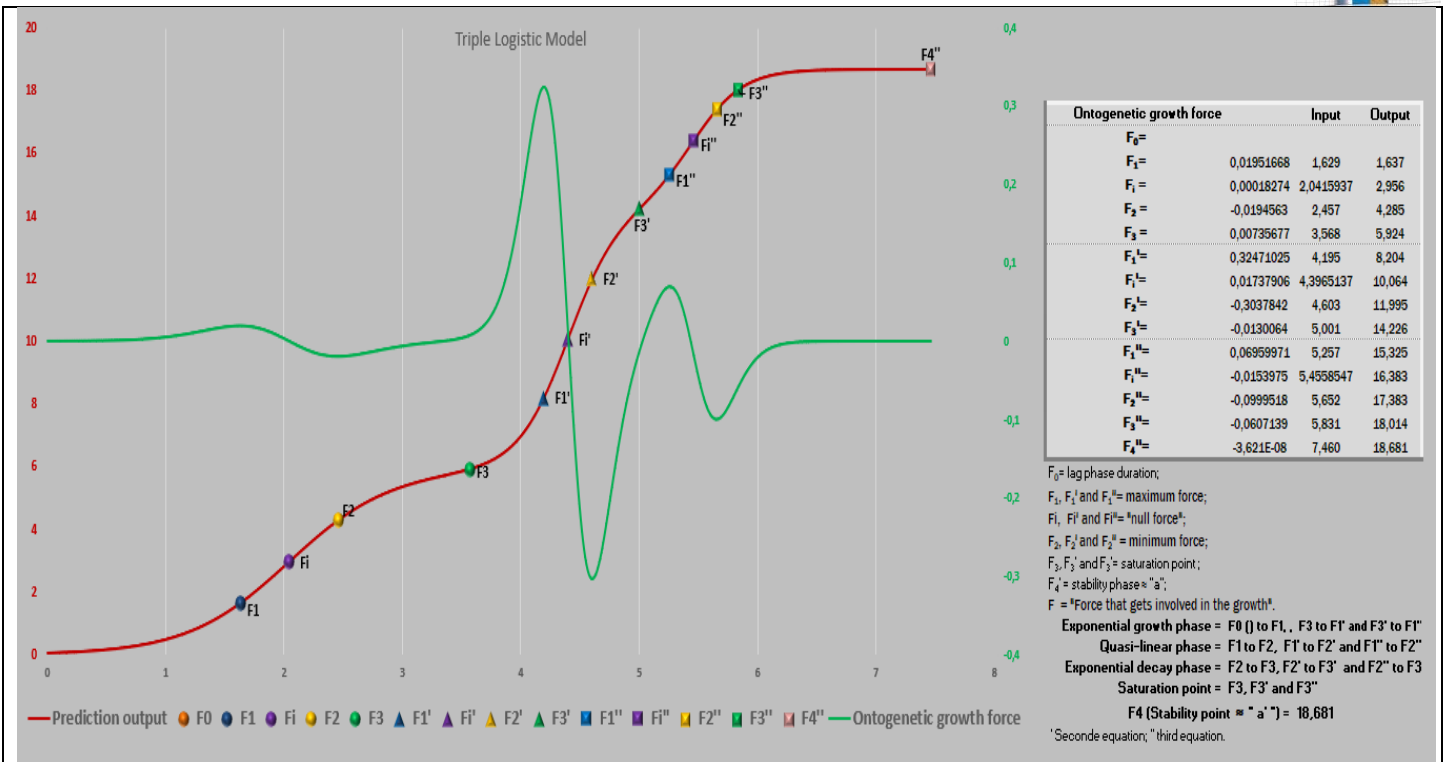
Functional Form

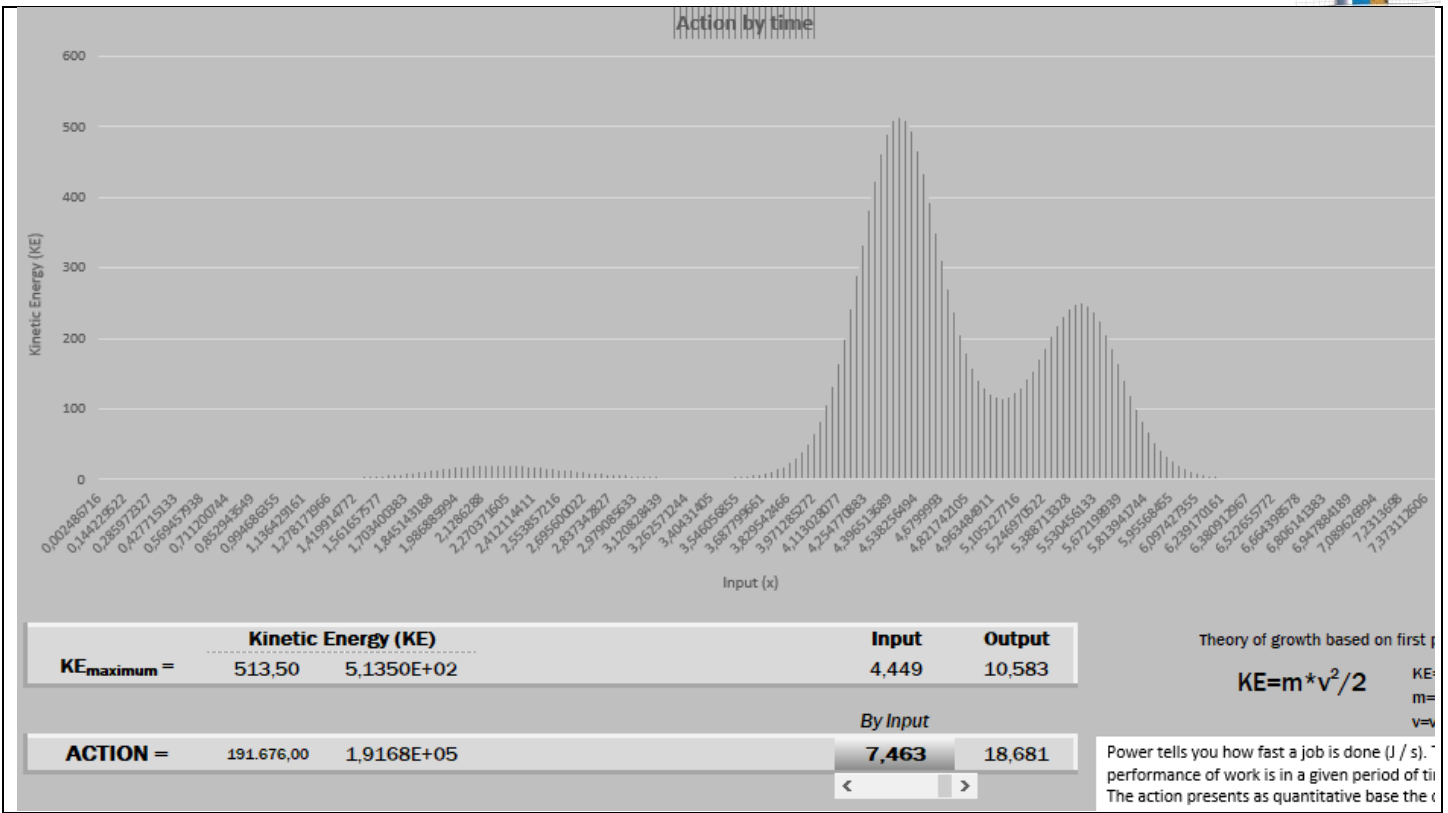
$$y = \frac{a}{1+e^{k(b-x)}} + \frac{a'-a}{1+e^{k'(b'-x)}} + \frac{a''-a'-a}{1+e^{k''(b''-x)}}$$

a'-a = 8,299848405
a''-a'-a = 4,455667214

Triple Logistic Model - Observed and Predicted Output





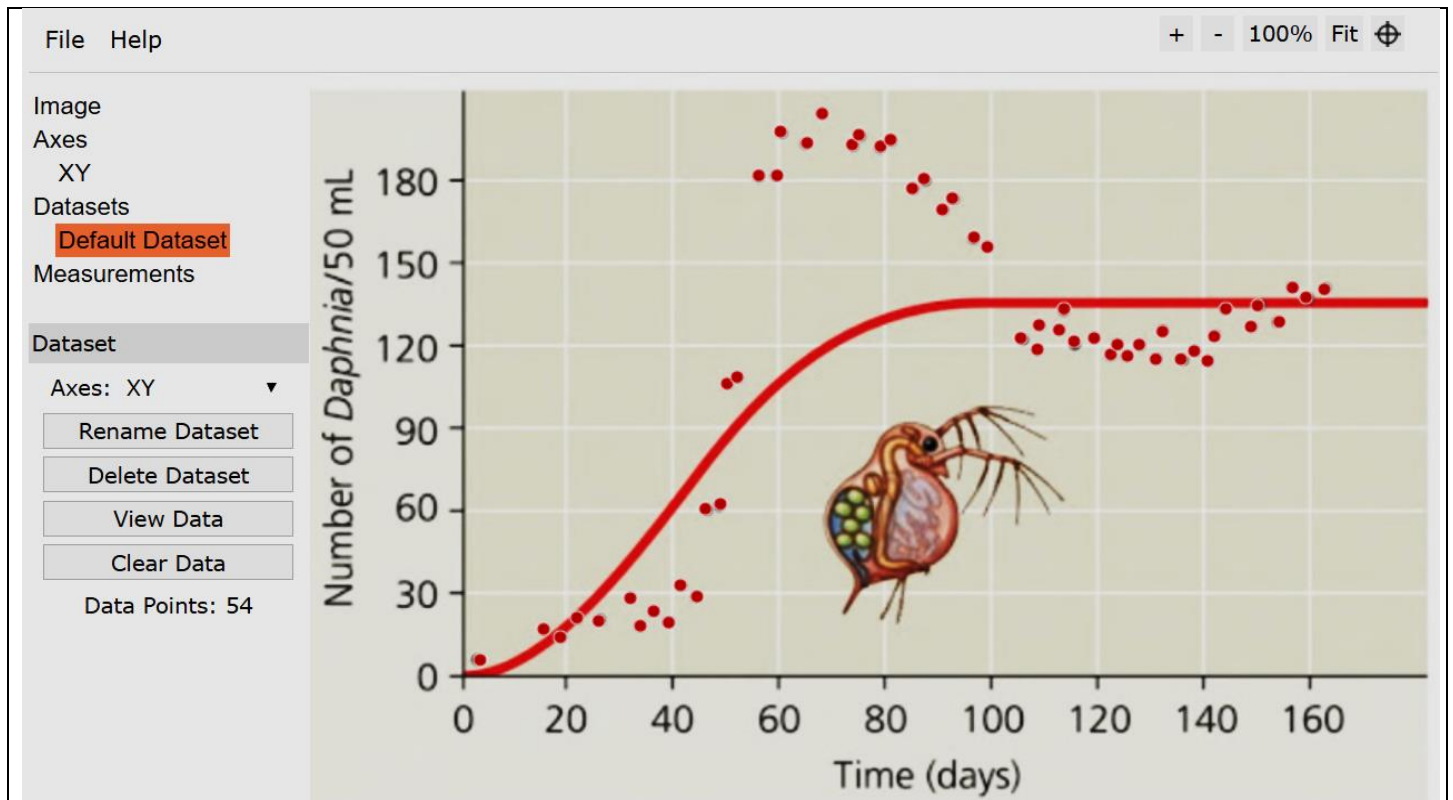




"A Daphnia population in the lab"

<https://www.lacesmagnetschool.org/ourpages/auto/2015/6/3/39944120/Ch53.pdf>

<https://apps.automeris.io/wpd/>





Fitting the Triple Logistic Model to Response Data

AIC_c = 239,523 BIC = 254,296

Point	Input (x)	Output (y)	Residuals	Expected	Qm
1	3,155819	6,47059	-8,4680	14,93862	4,8001
2	15,14793	17,6471	-0,3270	17,97409	0,006
3	18,30375	14,7059	-4,1206	18,8265	0,9019
4	21,45957	21,7647	2,0648	19,69986	0,2164
5	25,56213	20,5882	-0,2804	20,86865	0,0038
6	31,55819	28,8235	6,1206	22,70293	1,6501
7	33,45168	18,8235	-4,5495	23,36908	0,8842
8	35,97633	24,1176	-0,3348	24,45246	0,0046
9	38,81657	20	-6,3360	26,33604	1,5244
10	41,02564	33,5294	4,5146	29,01477	0,7025
11	44,18146	29,4118	-8,2670	37,67879	1,8139
12	45,75937	61,1765	14,8954	46,32103	4,7642
13	48,59961	62,9412	-11,3122	74,29336	1,7234
14	49,86193	106,471	14,3406	92,13001	2,2322
15	51,75542	108,824	-13,1280	121,9516	1,4132
16	55,85799	181,765	9,9444	171,8203	0,5795
17	59,32939	181,765	-7,1035	188,8682	0,2672
18	59,96055	197,647	7,2126	190,4345	0,2732
19	65,00986	193,529	-2,9534	196,0828	0,0333
20	67,8501	204,118	7,1520	196,9657	0,2997
21	73,53057	192,941	-3,9757	196,9168	0,0803
22	74,7929	196,471	-0,1196	196,9902	7E-05
23	78,89546	192,353	-2,0705	194,4234	0,022
24	80,78895	194,706	2,0174	192,6885	0,0211
25	84,89152	177,059	-9,7420	186,8008	0,5081
26	87,10059	180,588	-1,6525	182,2407	0,015
27	90,57199	169,412	-3,7217	173,1335	0,08
28	92,46548	173,529	6,1474	167,3821	0,2258
29	96,56805	159,412	5,1176	154,2942	0,1697
30	99,0927	155,882	9,1397	146,7426	0,5693
31	105,4043	122,941	-9,7679	132,7091	0,719
32	108,5602	118,824	-9,7334	128,9569	0,7369
33	108,8757	127,647	-0,5893	128,2323	0,0027
34	113,6095	133,529	8,6249	124,9045	0,5956
35	112,6627	125,882	0,5112	125,3711	0,0021
36	115,503	121,765	-2,4341	124,1988	0,0477
37	119,2899	122,941	-0,9301	123,4713	0,0023
38	122,4458	117,059	-6,2660	123,3248	0,3184
39	123,7081	120,588	-2,7541	123,3423	0,0615
40	125,6016	116,471	-6,9558	123,4264	0,392
41	127,8107	120,588	-3,0011	123,5893	0,0729
42	132,2288	125,294	1,2521	124,042	0,0126
43	130,9665	115,294	-8,6066	123,9008	0,5979
44	135,7002	115,294	-9,1630	124,4572	0,6746
45	138,2249	118,235	-6,5399	124,7712	0,3424
46	140,7495	114,706	-10,3810	125,0869	0,8615
47	142,0118	123,529	-1,7144	125,2438	0,0235

Sample Statistics			
Min Input	3,1598	Min Output	6,47
Max Input	162,8402	Max Output	204,12

Save
Menu

Regression										SSE
a	b	k	a'	b'	k'	a''	b''	k''		
57,09874062	51,061902	0,021657352	222,12936	51,061902	0,3795144	189,27395	94,433119	0,154239		2862,5682
-2,997940763	-24,87312196	-0,010219751	172,2265468	50,31272874	0,252681673	114,4759444	44,36572098	0,072336047		Lower 95% Confidence Levels
117,195422	126,9969254	0,053534456	272,0321672	51,81107466	0,506347045	264,0719571	144,5005175	0,23614205		Upper 95% Confidence Levels
30,66157214	38,74239901	0,016263828	25,46061743	0,382231103	0,064710954	38,16224814	25,54459096	0,041787246		Standard Errors
1,8622	1,3180	1,3316	8,7244	133,5891	5,8648	4,9597	3,6968	3,6911		t-Statistics
0,069108591	0,194178359	0,189689037	P<0,0001	P<0,0001	P<0,0001	P<0,0001	0,000590655	0,000600958		p-values
Goodness of Fit (R ² _{adj}) = 98,4041%		Qm = 36,1280082454854						critical X ² =		60,4808658

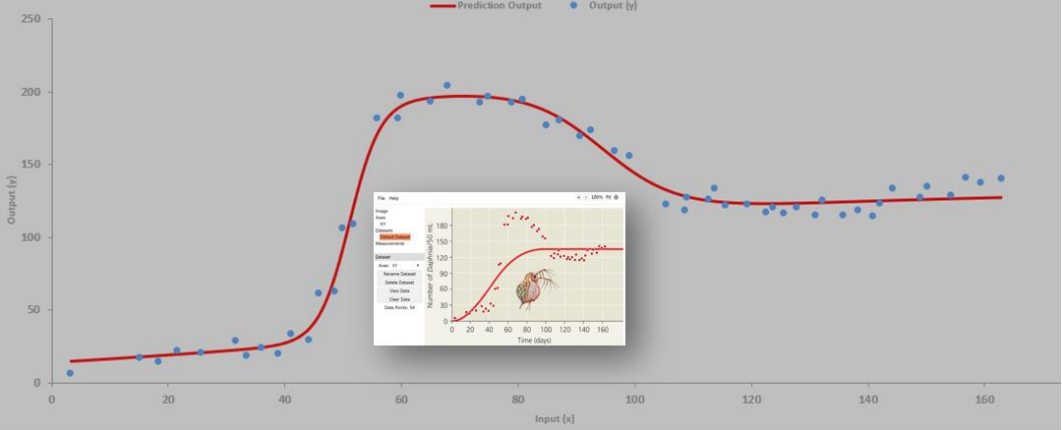
Functional Form

$$y = \frac{a}{1+e^{k(b-x)}} + \frac{a'-a}{1+e^{k'(b'-x)}} + \frac{a''-a'-a}{1+e^{k''(b''-x)}}$$

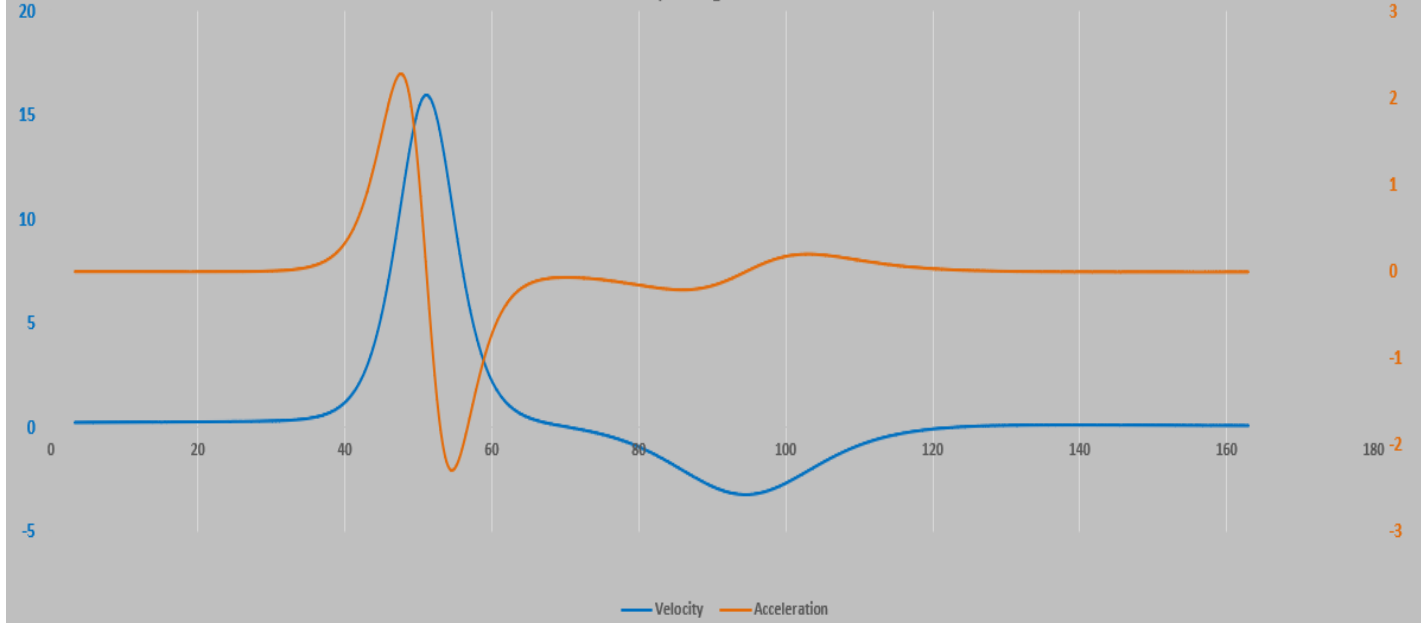
a'-a = 165,0306164
a''-a'-a = -89,95414691

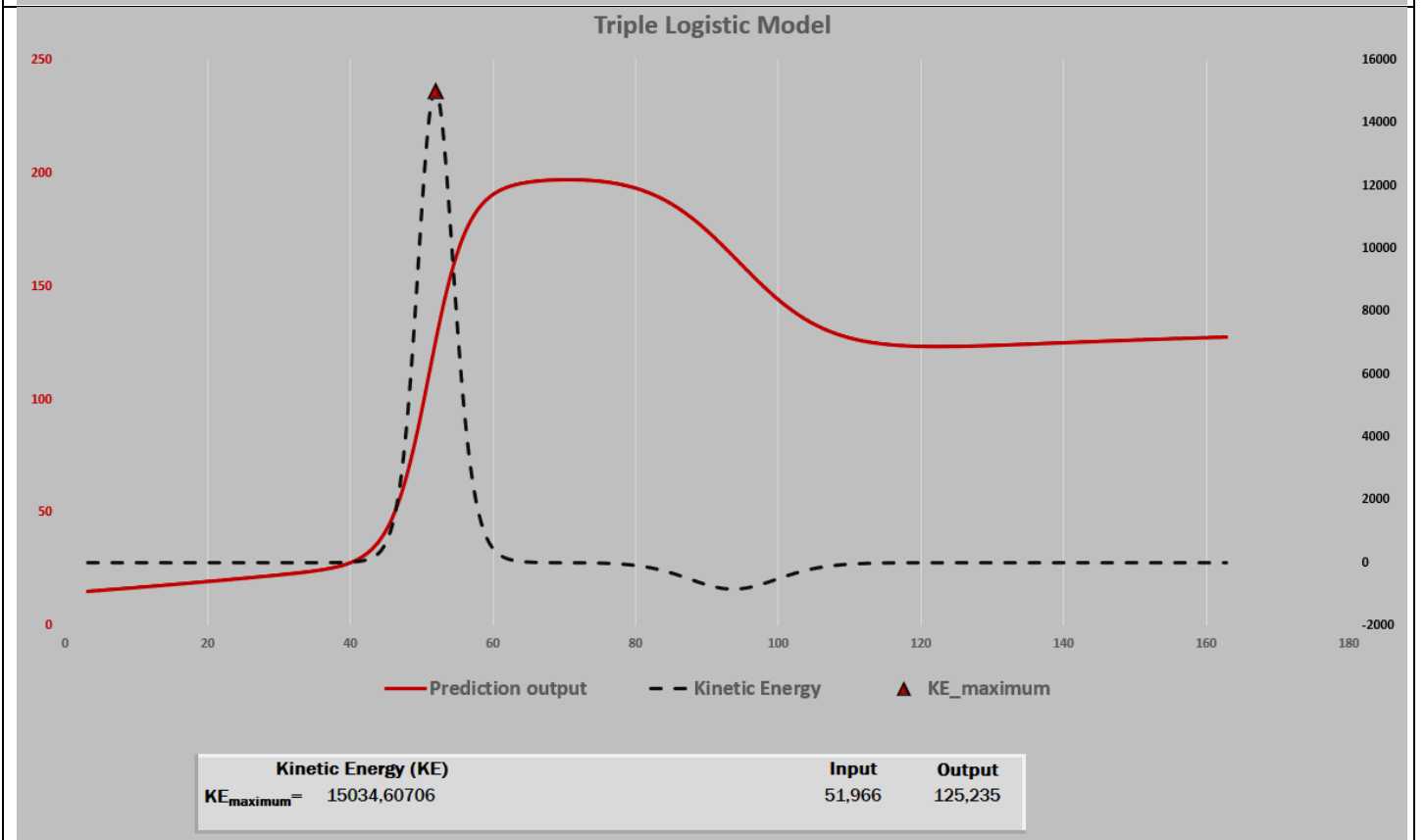
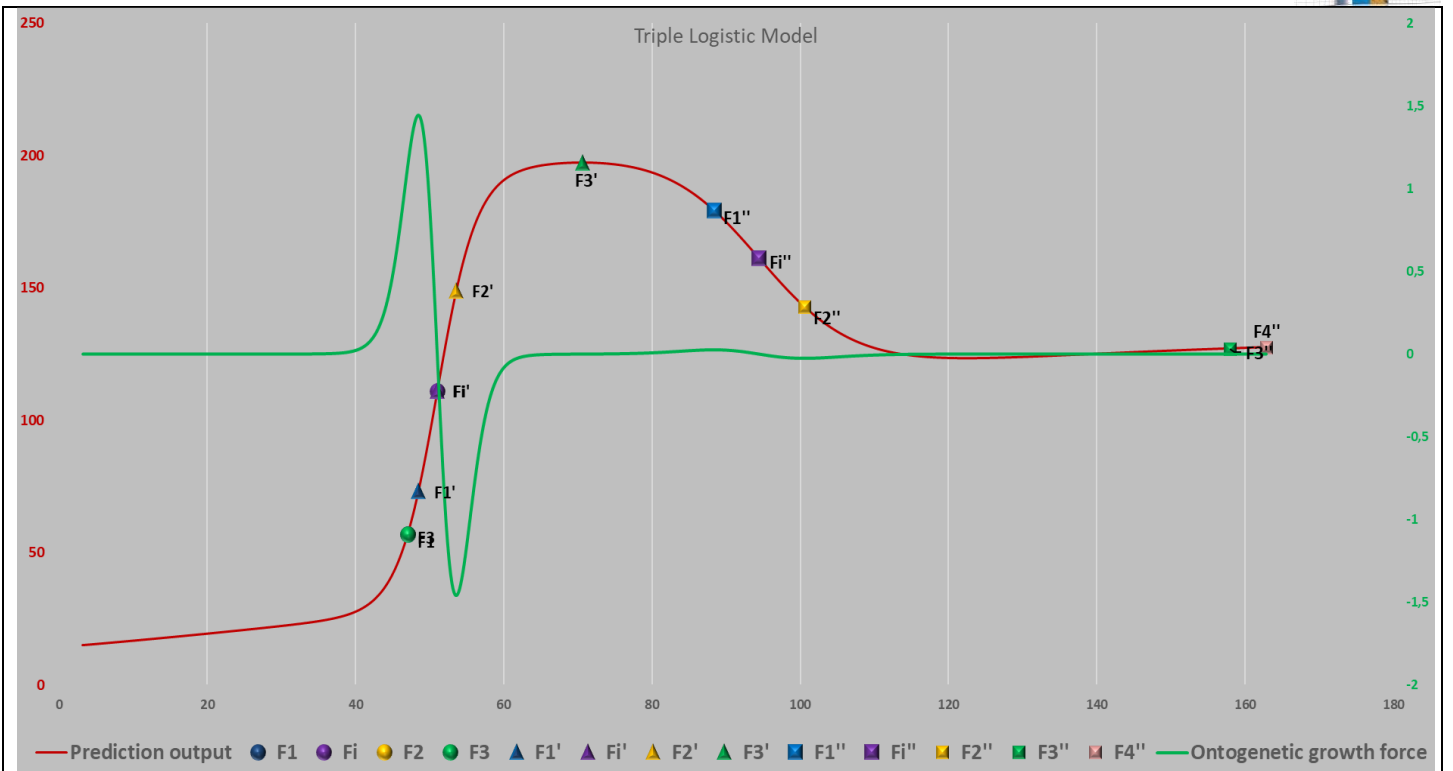
Regression models with Qm>critical X², indicating inadequate fits, are highlighted in red

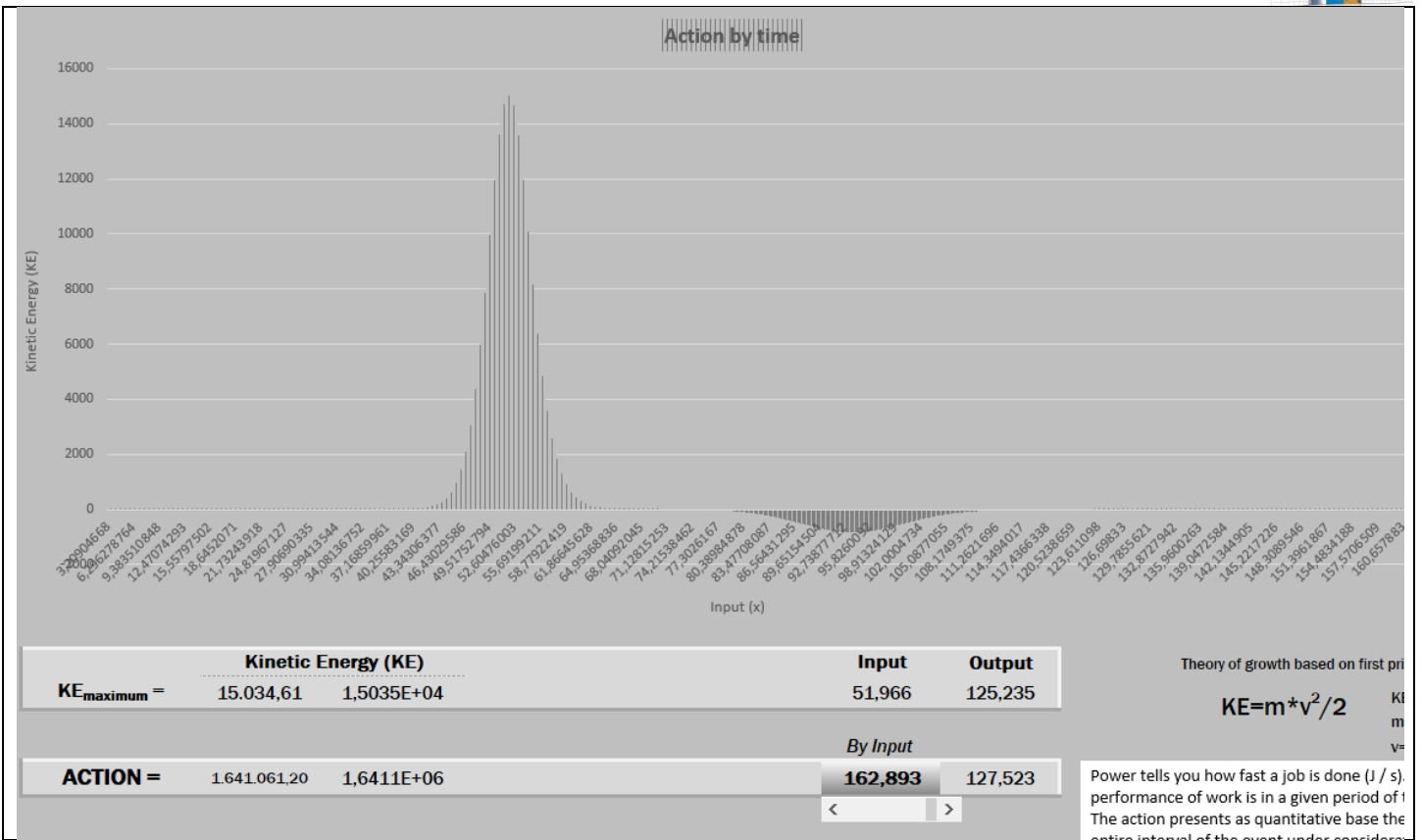
Triple Logistic Model - Observed and Predicted Output



Triple Logistic Model





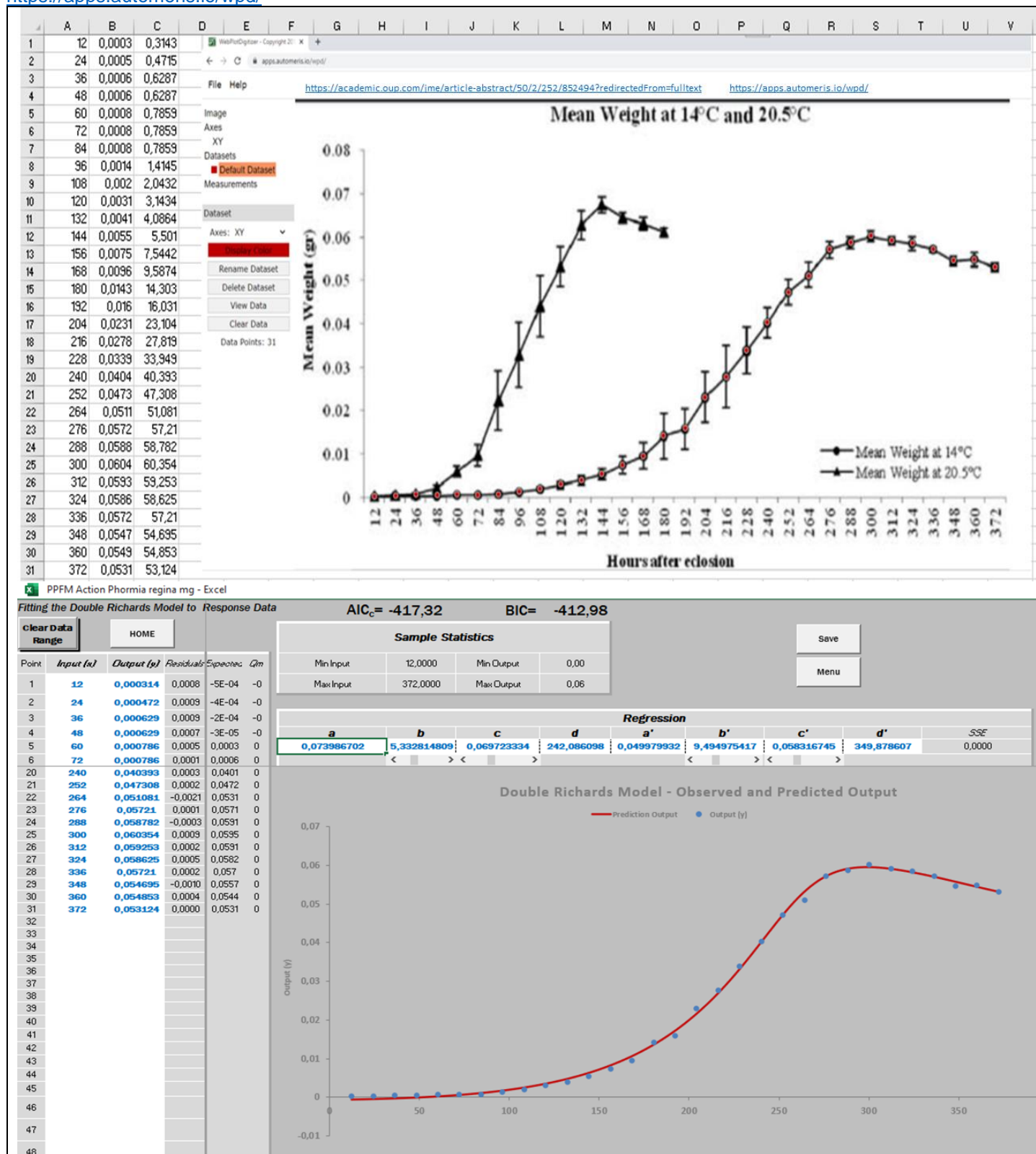


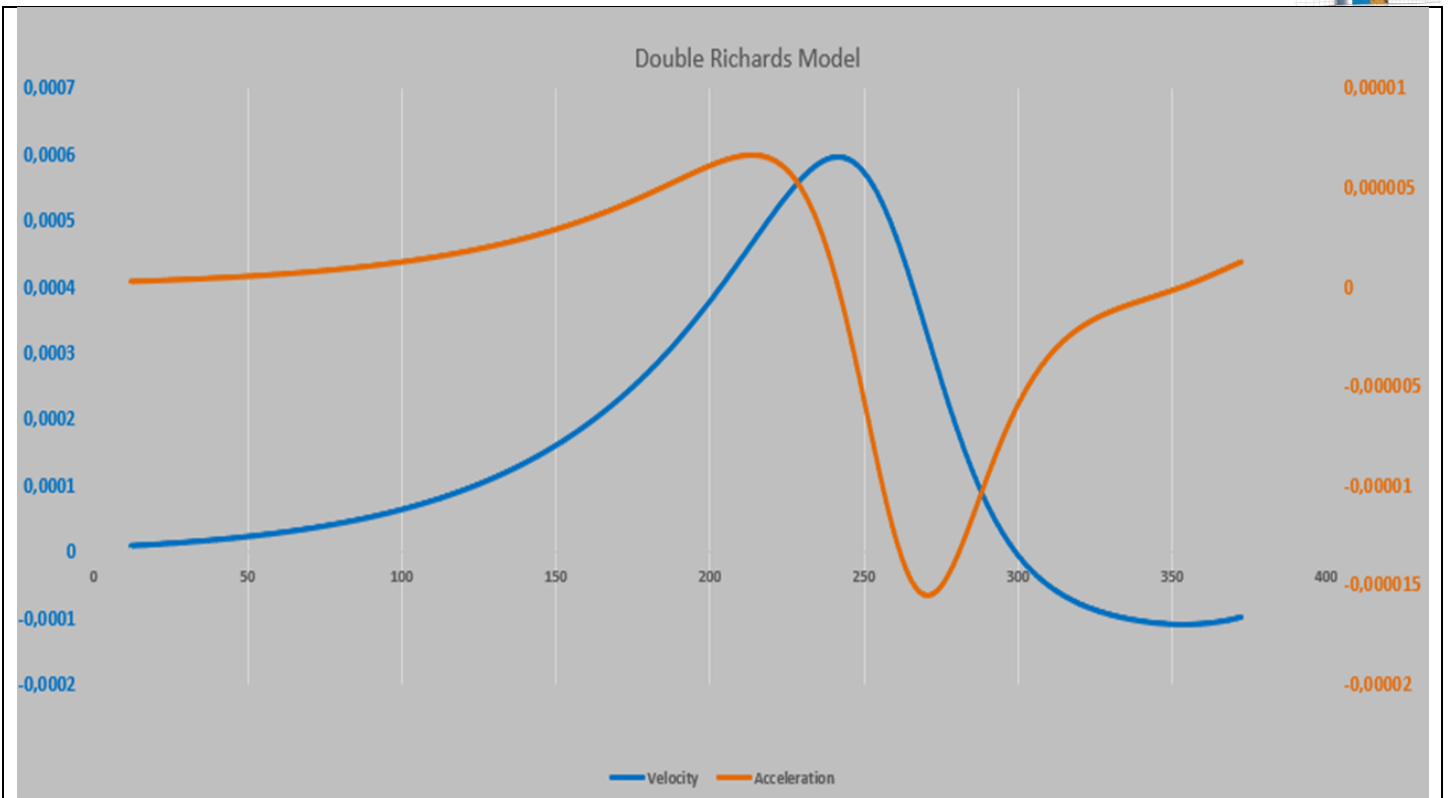


“Laboratory Development and Field Validation of *Phormia regina* (Diptera: Calliphoridae)”

<https://academic.oup.com/jme/article/50/2/252/852494>

<https://apps.automeris.io/wpd/>





$AIC_c = -417,32$ $BIC = -412,98$

Sample Statistics			
Min Input	12,0000	Min Output	0,00
Max Input	372,0000	Max Output	0,06

Stopping Critical point

100% 116%

Min Input: 12 Max Input: 431,52

Output: -0,0005 Output: 0,0502

Instructions

- Copy data in cells "Input and Output"
- View the data and estimate the value for "a, d, a' and d' "
- Guess values of "b, c, b' and c' " until the predicted line is close to the observed points

Regression							
a	b	c	d	a'	b'	c'	d'
0,073986702	5,33281481	0,069723334	242,086098	0,049979932	9,494975417	0,058316745	349,878607
SSE: 0,0000							

Ontogenetic growth force		
	Input	Output
$F_0 =$	0	168,481
$F_1 =$	4,5398E-10	220,501
$F_2 =$	-3,244E-11	242,0368
$F_3 =$	-8,631E-10	262,453
$F_4 =$	-3,435E-13	298,812
$F_1' =$	2,5893E-11	312,097
$F_2' =$	3,0244E-12	349,85344
$F_3' =$	-2,114E-11	382,576
$F_4' =$	-2,443E-12	421,731
$F_4'' =$	-9,13E-13	431,680

F_0 : lag phase duration;
 F_1 and F_1' : maximum force;
 F_1 and F_1' : "null force";
 F_2 and F_2' : minimum force;
 F_3 and F_3' : saturation point;
 F_4' : stability phase = "a";
 F = "Force that gets involved in the growth".

Exponential growth phase = $F_0 (0,01)$ to F_1
Quasi-linear phase = F_1 to F_2 and F_1' to F_2'
Exponential decay phase = F_2 to F_3 and F_2' to F_3'
Saturation point = F_3 and F_3'
 F_4' (Stability point = "a") = -0,001

* Secondo equation

