Future To effectively develop insects as food and feed, a first step should be to rehabilitate insects and leave the 'nasty, dirty and avoidable' image behind. This will require extensive information on the environmental and nutritional benefits as well as in assuring food safety aspects [13]. In the context of the positive change in the perception of insects as human food that we have seen in the western world in the past two decades, it is clear that a lot can be accomplished in the years ahead. Yet, much research needs to be done for this, especially in a multidisciplinary and transdisciplinary context. Topics to investigate include, e.g., production of insects on various rest stream, consequences for insect health and immunity, insects and food quality, economics, consumer behaviour, food technology, human health aspects, ethics and value chain development. Such studies will help to develop a new food sector that is likely to provide the growing human population with a novel protein source whose production is much more sustainable than current production of animal protein. Moreover, this new food sector also has excellent opportunities to contribute to achieving various of the global development goals [14,15].

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Industrial insect production as an alternative source of animal protein

Antoine Hubert
Ÿnsect, 1, rue Pierre-Fontaine, 91000 Évry, France
E-mail address: antoine.hubert@ynsect.com

By 2050, the World Resources Institute projects a 70% human food calorie gap [1]. The race for sustainable protein alternatives is heating up and to avoid global issues, the world needs massive productivity increases in protein production. The FAO expects insect protein could help close the gap [2,3]. The European insect sector (Fig. 1) is an emerging industry, which concentrates on research and innovation efforts that are invested in the sustainable protein sector worldwide. Legislative decisions taken by EU policy makers constituted decisive factors that contributed to boost the advancement of the sector. We urgently need to address the entire food chain and make it possible to produce a better, high-quality product–with lower cost inputs. This means zeroing in on earlier stages of the food production process: namely how farmed fish and, ultimately, poultry and cattle are fed. Livestock consume roughly 20% of global proteins and compete with humans for ocean fish stocks, water, land, and soil resources (FAO, 2016). Poultry, pigs, aquaculture and some pets are fed diets that include fishmeal and fish oils, which are produced from ocean-caught fish and fish trimmings. Aquaculture plays a critical role in human nutrition, growing faster than any other protein source for human consumption. Around half of the fish we eat today comes from farmed sources. Yet fishmeal, the primary food source for farmed fish, is in crisis because it is derived from fast-depleting ocean fish stocks.

By replacing traditional animal and fish-based diets with insect protein, we can offset the growing competition for the ocean fish stock required to be able to feed 2 billion more people by 2050. This further serves to reduce fish, water, and soil depletion, as well as agriculture's 25% share of global greenhouse gas emissions. Insects are part of a natural diet for fish, birds and some mammals; they contain high levels of essential proteins and nutrients, which are optimal for animal growth. Today, the feed given to farmed animals does not include this sustainable protein.

However, due to the rising costs of traditional feed ingredients, coupled with the increased production of farmed fish, feed nutritionists and manufacturers have reduced the amount of fishmeal in aquaculture diets, replacing it with plant-based ingredients, especially soy. Mostly imported to Europe from the Americas, soy bean production carries a huge environmental cost resulting in, among other things, deforestation and soil erosion. It is pretty crazy to be feeding the animals we eat with one of the most expensive forms of protein in the world. This

Fig. 1

is why we need to focus on the start of the food chain. Insects could make up the protein shortfall without requiring us to acquire dramatic new tastes in food.

Insects can be a sustainable alternative to soy and fishmeal in particular. Not only are insects already part of the natural diet of cattle, pigs, poultry, and fish, but insects deliver an important source of high-quality protein and polyunsaturated fats.

Farming insects is also hugely cost-efficient and suitable for many climates. I first began breeding Molitor/mealworm larvae at Ÿnsect, the company I co-founded in 2011, and discovered just how energy efficient it was. Insects require very little water, can be grown in the dark all year round, have no impact on sea or freshwater biodiversity, and even lead to improvements in land use productivity.

Specialists and scientists have known about the Molitor species for a long time. The mealworm (the larval form of the Tenebrio Molitor beetle) is comprised of more than 70% protein and is a natural source of nutrients for a wide array of animals, including fish, poultry, pigs, dogs, and cats.

It is also the insect species most suited to industrial development. It is a naturally gregarious, nocturnal species, which, from a practical standpoint, makes breeding easier. It brings real added value to the market for alternative protein sources thanks to its nutrient-packed content and unique health benefits for plants and animals.

Our chosen technology and insect species allow us to fully focus on sustainable development: to do more with less; to use fewer resources to feed plants and animals; to use fewer antibiotics and pesticides; to reduce our physical footprint.

Given its intrinsic qualities, the Molitor is perfectly placed to promote a circular economy. The mealworm consumes all sorts of organic matter, even low-grade materials. It grows quickly and requires less space, less earth and less water than other animal protein sources. It also releases less ammonia and fewer greenhouses gases than other premium animal proteins. The entire production system is modelled on a circular economy with zero-waste. The Molitor protein is produced using fewer antibiotics and chemical fertilizers and the final product is 72% protein, with proven nutritional and health benefits for aquaculture and pets. With two billion more people to feed within a matter of 30 years and fish being the fastest-growing source of protein for human consumption globally, insect protein can play a pivotal role in closing the gap.

I envision a time when insect protein is at the start of the food chain for almost everything consumers eat. And even our plants will be supercharged with fertilizers derived from insects applied to increase yields.

Putting insects back to their rightful place at the start of the food chain will give our planet much more breathing space than misguidedly trying to force everyone to give up meat and dairy. With insect farming, we are creating a new and highly sustainable agrifood industry, backed by extremely innovative tried-and-tested production facilities. Hopefully, the big brand beasts at the top of the global food chain will soon realize this, and will back the logical solution to the protein crisis rather than simply jumping on the popular bandwagon.

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The impact of climate on the winter strategies of insects

Joan van Baaren
UMR-CNRS 6553 ECOBIO, Rennes University, France
E-mail address: joan.van-baaren@univ-rennes1.fr

Life-history traits within ecological communities can be influenced by two opposite pressures, the first one being community-wide density-dependent processes like competition (internal filters), and the second regional environmental conditions (external filters). While species belonging to a guild may present contrasting traits as a means of niche differentiation, allowing coexistence whilst exploiting the same resources, traits in a regional context may converge to a narrow range of values because of environmental filtering [1]. As ectotherm organisms depend strongly on temperatures, convergent winter strategies could be expected in insects of the same area. In temperate areas, insects can escape the stressful winter conditions either by (i) migration, (ii) diapause (i.e. arrest of development), or (iii) remaining in activity by producing cryoprotectant molecules. Concerning the diapause strategy, it was shown that temperature is both a selective pressure and a modulator of the diapause expression in insects. Thus, with climate warming, and especially winter warming, which acts at the community level, a convergent alteration of the response to seasonal changes is expected for the ectotherms, either through genetic adaptations to novel climatic conditions or through phenotypic plasticity.

In a first study [2], we observed the loss of diapause strategy in two species of an aphid-parasitoid community. Since the 1980s in western France, the winter guild of aphid parasitoids (Hymenoptera: Braconidae) in cereal fields has been made up of two species: *Aphidius rhopalosiphi* and *Aphidius matricariae*. The recent activity of two other species, *Aphidius avenae* and *Aphidius ervi*, during the winter months suggests that a modification of aphid parasitoid overwintering strategies has taken place within the guild. In this study, we first performed a field survey in the winter of 2014/2015 to assess the levels of parasitoid diapause incidence in agrosystems. Then, we compared the capacity of the four parasitoid species to enter winter diapause under nine different photoperiods and temperature conditions in the laboratory. As predicted, historically winter-active species (*A. rhopalosiphi* and *A. matricariae*) never entered diapause, whereas the species more recently active during winter (*A. avenae* and *A. ervi*) did enter diapause, but at a low proportion (maximum of 13.4 and 11.2%, respectively). These results suggest rapid shifts over the last three decades in the overwintering strategies of aphid parasitoids in Western France, probably due to winter warming. This implies that diapause can be replaced by active adult overwintering. The mechanism behind the change of overwintering strategy seems to be more a decrease in responsiveness to environmental signals rather than a genetic loss of diapause. This plasticity allows non-diapausing individuals to increase their progeny production. A meta-analysis dedicated to animals has shown that most of the responses to environmental changes involved phenotypic plasticity rather than genetic evolution. Moreover, when genetic changes or shifts in demography, distribution or phenology occurred, these were generally preceded by a modification involving phenotypic plasticity. Thus, behavioural plasticity appears important in explaining the variation in the success of species to resist to environmental changes.

We confirmed this evolution of winter strategy in our aphid–parasitoid system, by using a nine-year dataset to build trophic webs. We confirmed that the community structure and composition that prevailed before 2011 have recently shifted toward a more diversified community, with the presence of the two new braconid parasitoid species studied before