Co-developing Pest Management for Organic Apple Production

Combining Participatory Action Research, Activity Theory, Laboratory and Field Trials in a Swedish Context

Weronika Świergiel

Faculty of Landscape Architecture, Horticulture and Crop Production Science
Department of Plant Protection Biology
Alnarp

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Cover: Flower strip observational trial for enhancement of natural enemies in a Swedish apple orchard.
(photo: Weronika Świergiel)

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Abstract

Participatory Action Research (PAR) is an interventionist, action-orientated and transdisciplinary approach to applied research that strives for the collaborative development of any practice together with relevant stakeholders. It enhances the relevance of research to practice by active stakeholder involvement in all research steps, including the spaces in which the practice is conducted, its iterative knowledge construction and the recognition that knowledge exists in practice and is created when attempting to transform reality.

During the PAR project on pest management in Swedish organic apple production on which this thesis is based, several pests and control methods were addressed, focusing mainly on the apple sawfly (*Hoplocampa testudinea* Klug). An interdisciplinary methodology and PAR approach was employed, including participatory meetings, interviews and field and laboratory experiments.

An efficient control method was developed involving a forecasting model in combination with a botanical pesticide derived from *Quassia amara* L. However, the potential negative side effects of *Q. amara* on natural enemies are currently being evaluated by the European Union.

Control of the apple sawfly by soil application of the entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin was found to be insufficient in the field trial and requires further studies to bridge the gap between laboratory and field results. *B. bassiana* persistence was found to be high during the apple sawfly descent to the soil and negligible after a year.

During the project a need emerged to find a theory and tools that could support participatory problem formulation by identifying the systemic root causes of the pest problems being experienced and explain the main drivers of this development. It was assumed that this would facilitate the development of more sustainable solutions. Cultural-Historical Activity Theory (CHAT) offered these tools and was applied as a retrospective analytical lens on the PAR project. I analysed the emergence and development of organic apple production in Sweden and formulated a hypothesis on the root causes of disturbances reported in pest management by farmers growing organic apples. The results suggest that the formulation of pest management problems during the previous PAR project focused on development of tools to increase productivity. However, based on the historical root causes of the problems, identified by the CHAT-based analysis, a wider systemic approach is required to find sustainable solutions.

Keywords: systemic thinking, sustainable development, contradiction manifestations, developmental dimensions, biological control, integrated pest management, Beauveria, organic orchard, forecasting, monitoring

Author's address: Weronika Świergiel, SLU, Department of Plant Protection Biology, P.O. Box 102, 230 53 Alnarp, Sweden
E-mail: Weronika.Swiergiel@slu.se

Dedication

To my lifelong and ever changing team without whom none of this would have happened.

Nothing is as practical as a good theory.

&

The best way to understand something is to try to change it.

Kurt Lewin

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Świergiel, W., Pereira Querol, M., Rämert, B., Tasin, M., Vänninen I. An Activity-Theoretical view on pest management development in apple production within a Participatory Action Research project. (Manuscript).

II Sjöberg P., Świergiel W., Neupane D., Lennartsson E., Thierfelder T., Tasin M & Rämert B., 2015. Evaluation of temperature sum models and timing of *Quassia amara* (Simaroubaceae) wood-chip extract to control apple sawfly (*Hoplocampa testudinea* Klug) in Sweden. *Journal of Pest Science,* 88(2), 301-310.

III Świergiel W., Meyling, N.V., Porcel, M., Rämert, R., 2015. Soil application of *Beauveria bassiana* GHA against apple sawfly (*Hoplocampa testudinea* Klug; Hymenoptera: Tenthredinidae): field mortality and fungal persistence. *Insect Science,* doi: 10.1111/1744-7917.12233.

All papers are or will be published with Open Access.

The contribution of Weronika Świergiel to the papers included in this thesis was as follows:

I Planned and performed the participatory action research process with help from co-authors. Analysed data and wrote the paper together with co-authors.

II Planned and performed field experiments with help from co-authors. Analysed data and wrote the paper together with co-authors.

III Planned and performed field and laboratory experiments with help from co-authors. Analysed data and wrote the paper together with co-authors.

1 Introduction

Farming has suffered a declining role in Swedish society ever since World War II. Through the intensification or rationalisation policy following World War II, the state expected the labour force to move into the expanding industrial complexes in cities and exploitation of natural resources in northern Sweden (Domeij, 1995; Höglin, 1998). Hence farming was not given the role of an engine for rural employment and development. However, national self-sufficiency in food production was highly prioritised until the end of the 1980s (Domeij, 1995), at which time agriculture was included in the General Agreement on Tariffs and Trade (GATT) and deregulated (Stewart, 1999; Rabinowicz, 2004). Consequently, farming was assumed to act according to profit maximising principles on an open market where land and food were simple commodities with no special rights. These policies contributed to a 79.6% decrease in the number employed in farming from 1951 to 2007 (SCB, 2015a), while farmland area decreased by 28.7% in the same period (SCB, 2015b). By 2007, only 4% of the Swedish labour force worked with farming for at least part of the season (SCB, 2015a, c). From 1944 to 2007, the total arable land area decreased, small and medium-scale farms disappeared and land was concentrated to farms larger than 100 ha (SCB, 2015b, d). To a large extent due to these changes, increased labour productivity was achieved through intensification of farming, although at the cost of drained rural communities (Milestad et al., 2010; Kjörling, 2011; Darnhofer, 2014).

The mainstream agriculture developed over the past 70 years has played an important role in environmental degradation (MEA, 2005). Moreover, the domination of regional specialisation, large-scale food chains and the increasing distance between food producers and consumers is associated with large environmental costs in terms of transportation, storage and waste and increasing problems with closing nutrient cycles (Darnhofer, 2014). For example, Swedish food consumption was estimated to rely on 40% imports in

2003 (Carlsson-Kanyama & Engström, 2003). Fruits, berries and nuts is the largest group of imported foods, with apples being the second largest fruit import (Lindgren & Fischer, 2011).

Reductionist research and the linear transfer of technology concept achieved increased labour productivity, but did not manage to simultaneously address the multiple functions of farming that include sustainable livelihoods, rural development and strengthening the natural resource base and ecosystem services (Altieri, 1995; Allen & Kovach, 2000; Röling, 2009). In response, an agroecological approach has developed where the entire food system is taken into consideration including its social and environmental aspects, and where more localised food systems are promoted (Carporal & Azevedo, 2011). Agroecology subscribes to Participatory Action Research (PAR) methodologies as a means to address the real needs and complexity of food systems (Foot Whyte, 1991; Röling, 2009; Carporal & Azevedo, 2011).

Research on rural sociology in industrialised countries, including Sweden, shows that organic agriculture is contributing to a more diverse rural population with higher female participation, increasingly diverse job opportunities due to higher use of local resources, more social interactions with farm visitors, interns, associations and local food chain networks, and a higher labour requirement in the production and diversification into food processing, sales, landscape management and tourism (Domeij, 2007). Furthermore, research on Swedish experiences has shown that selling locally is a driving force for increased on-farm biodiversity (Björklund et al., 2009).

There is an increasing number of organic farmers in Sweden, which has created a need to address the challenges they encounter. Pest damage is one of the major risks of organic farming and hence a barrier to starting and continuing production. It has been widely argued that to achieve efficient farming systems, including pest management, that strengthen instead of weaken the multiple functions of farming, a collaborative and interdisciplinary approach is required (Altieri, 1995; Noe et al., 2008; Röling, 2009). This thesis is seated within this discourse, i.e. supporting the development of pest management in organic apple production through a PAR approach.

1.1 Development of organic farming in Sweden

Farming based on ecological principles started to develop decades before World War II and has influenced organic farming (OF) (Darnhofer et al., 2010b), which emerged mainly as an answer to the economic, environmental and social problems caused by rational productivist agriculture (Altieri, 1995; Allen & Kovach, 2000; Rigby & Cáceres, 2001; Röling, 2009).

Until the 1970s, the focus of alternative agriculture was mainly on product quality of nutrient-rich and pesticide-free food (Domeij, 1995). During the 1980s the lower yields in OF were also seen as a solution to overproduction, while simultaneously addressing the increasing environmental problems (Domeij, 1995). In 1985, the Federation of Swedish Alternative Farmers (FSAF) and the certification organisation for alternative farming (KRAV) were formed (KRAV, 2015).

At a meeting of the Nordic branch of the International Federation of Organic Agriculture Movements (IFOAM) in 1989, OF was defined as: "a self reliant, sustainable agro-ecosystem, based on local and renewable resources […] on a holistic view where nature is considered as a whole with an intrinsic value of its own. Further, humankind is to take moral responsibility regarding the ecological, economic and social aspects of agricultural production" (Granstedt et al., 1998:38).

The increasing costs of production and decreasing prices caused by rationalisation and free market policies led conventional growers to consider the premium prices and subsidies of OF as an innovation that could provide temporary relief from the price pressure (Domeij, 1995). Between 1988 and 1995, there was a 3.7-fold increase in organic farmers and a 10-fold increase in percentage of organic agricultural area (Rydén, 2003).

The rapid growth of OF caused a crisis. First, for many conventional farmers converting to OF, the economic aspects dominated their motivation and they preferred OF to remain as a market niche with premium prices. This conflicted with the desire of more environmentally motivated farmers for a FSAF acting to transform the entire farming system according to ecological principles (Rydén, 2003).

The second reason of the crisis was that OF had not developed its own food distribution concept and associated rules based on ecological principles that would be able to offset the increasing amount of organic produce (Rydén, 2003). This urgent need was solved by selling through the conventional food chains adapted to specialist, large-scale, industrial bulk production of standard quality (Goodman, 2000; Allen & Kovach, 2000; Darnhofer, 2014). Their domination of the food system, together with the consumer preference for shopping in their supermarkets, pushed prices down and was associated with large environmental costs for transportation, storage and waste, irrespective of whether the food was conventionally or organically produced (Darnhofer, 2014).

To fully integrate organic principles with economic viability, societal commitment was needed for e.g. the recirculation of nutrients, renewable energy and fuel, reimbursement for managing common goods, etc. (Domeij, 2007; Kahiluoto et al., 2005; Darnhofer et al., 2010a). Lacking such support, farmers often felt forced to compromise the long-term sustainability and resilience of their farm to obtain short-term profitability (Allen & Kovach, 2000; Darnhofer et al., 2010b). Consequently, many farmers originally resisting the conventional food chains chose to join them as a means of economic survival (Darnhofer et al., 2010a). The need to adapt to deregulation policies and the requirements of the conventional food chains contributed to the creation of a hybrid system, intensive organic farming (IOF), where some sub-activities were guided mainly by ecological and social principles while others were guided by rationalisation and profit maximisation principles (Darnhofer, 2014; Allen & Kovach, 2000). This normally involved specialising in fewer crops, increasing external inputs and introducing mechanisation to manage labour peaks (Darnhofer et al., 2010a).

When organic farms move from a high level of local self-sufficiency of renewable inputs to specialisation with increased mechanisation and long food chains, they lose much of their power to be strong engines for rural development and food sovereignty in their communities and create lower, but similar, levels of resource use with energy-intensive inputs and related problems such as decreasing biodiversity found in conventional production (Goodman, 2000; Björklund & Johansson, 2010; Darnhofer et al., 2010a; Milestad et al., 2010; Darnhofer, 2014).

Some farmers have looked for alternative solutions to these problems that will allow for profitability and still advance the principles of multifunctionality and ecological sustainability of farming. This development builds on re-designing the food system to be based on local community cooperation and food sovereignty, sharing of knowledge, machinery, labour and risks with other growers and consumers in community-supported agriculture concepts (Milestad & Kummer, 2012; Darnhofer, 2014) and through community and direct sale-based certification systems called participatory guarantee systems (Källander, 2011). Similar emerging and experimenting development is occurring world-wide, some of it under the name of agroecology (IAASTD, 2008; Wezel et al., 2009). Agroecology has evolved from a study of ecological interactions in the field to a farm level re-design and since the turn of the century the focus is on the redesign of the whole food system, called Ecology of the Food System, where rural-urban development, food production and ecological principles all merge under the concept of food sovereignty (Patel, 2009; Wezel et al., 2009).

1.2 Organic pest management in Swedish apple production

In Sweden, fruits are grown on 13% or 1444 ha of the total horticultural production area, excluding greenhouses. Apples dominate, occupying 87% of this area. In 2014, organic apples were produced on 140 ha or almost 10% of the total Swedish apple production area (SJV, 2015a, b).

Long-term preventative solutions for pest problems are essential for organic pest management, since monocultures and extensive use of reactive solutions to pests and nutrient supply, instead of preventive solutions, are causing low ecological resilience and higher dependence on external inputs such as (botanical and mineral) pesticides to achieve high yields (Altieri et al., 2012; Ponisio et al., 2014). Zehnder et al. (2007) modified a conceptual model for organic pest management originally proposed for organic apple production by Wyss et al. (2005). The model suggests four phases of organic pest management combining a diversity of strategies from indirect preventive measures designed into the cropping system, to direct and curative measures only when previous methods fail. The first phase is dedicated to cultural practices aimed at preventing pest infestations and damage such as crop rotation, soil management, non-transgenic host plant resistance and farm/field location. To strengthen the effects achieved by the first phase measures, the second phase strategies are based on vegetation management to enhance the biological control potential of natural enemies by providing them with food and shelter (Conservation Biological Control, CBC) or to directly interrupt the host finding, oviposition or life cycle of pests through different intercropping practices. The third phase proposed by Zehnder et al. (2007) is the release of biological control agents and the fourth is the use of approved pesticides of biological and mineral origin and of pheromone and kairomone techniques. However, it should be noted that this pest management model is a general model that needs to be critically examined in each case.

Paper I shows that it is important to bear in mind that the perceived need to apply potentially harmful direct and reactive pest control will not only depend on the efficiency of the control strategies in the first phases. The societal value given to more socially and environmentally friendly control measures is transformed into political decisions, consumer choices and risk management strategies, which create more or less favourable conditions allowing avoidance of potentially harmful pest control measures. Feasible and desirable pest management strategies can therefore not only be developed by focusing on their efficiency.

Based on the work of the PAR group described in this thesis, the work of other researchers on pest management in Swedish apple production and current pest management recommendations by the Swedish Board of Agriculture, the most severe pest problems and existing and emerging pest management strategies according to the conceptual model suggested by Zehnder et al. (2007) are presented below.

The most serious pests in Swedish organic apple production are apple scab (*Venturia inaequalis* (Cooke), Wint.), the most severe fungal disease damaging leaves and apples; fruit tree cancer (*Neonectria ditissima* (Tul. & C. Tul.) Samuels & Rossman), a fungus disease attacking the woody tissues of apple trees and apples during storage; apple sawfly (*Hoplocampa testudinea* Klug) which damages apples (further described in section 4.1); apple fruit moth (*Argyresthia conjugella* Zeller), winter moth (*Operophtera brumata* L.) and complex of tortricids including codling moth (*Cydia pomonella* L.) which all cause damage to leaves and/or apples and finally the rosy apple aphid (*Dysaphis plantaginea* Passerini), which is a cyclical pest causing occasional severe damage to apples and woody tissue of apple trees.

1.2.1 First phase of organic pest management

In recent years, the commercial farmers involved in the PAR group have observed failure of resistance in previously scab-resistant cultivars. Therefore robust rather than resistant cultivars are now recommended to organic farmers (SJV, 2015c). The farmers also reported using tillage in autumn to shred and cover fallen leaves with soil, in order to interrupt the fungus life cycle.

Fruit tree cancer is a serious disease with no available pest control products in organic farming (SJV, 2015c). Moreover, at the present time it is not possible to buy certified trees free from fruit tree cancer. However, an early DNA-based detection method is under development, as is breeding for more scab and fruit tree cancer-tolerant cultivars (Ghasemkhani, submitted; Garkava-Gustavsson, in press). Some preventative measures include ensuring good soil drainage, avoiding surplus nitrogen fertilisation, monitoring, and sanitation of apple trees and hedges with broadleaved trees (Świergiel et al., 2010). According to the apple advisor participating in the PAR group, damaged trees up to three years old should be replaced, while damages to older trees should be cut away and the wounds protected with clay and ion-based paste.

1.2.2 Second phase of organic pest management

The rosy apple aphid can be a severe pest in certain years. There are currently no efficient control products available in Sweden (SJV, 2015c). Together with farmers, our research group is developing knowledge about the seasonal occurrence of natural enemies of this pest in order to enhance natural biological control through pesticide avoidance (Porcel et al., in press), vegetation management and possibly by preventing ants from protecting the aphids from natural enemies (Pålsson, pers. comm. 2015). In addition, ongoing trials on farms are investigating the biological control potential of flower strips for a range of common pests.

1.2.3 Third phase of organic pest management

No insect biological control agents and very few microbiological products are permitted for release in Swedish agricultural fields (SJV, 2015c). Tortricids are controlled by granulovirus or *Bacillus thuringiensis* products depending on the species (*ibid*). Nematode products and antagonistic fungi are available (*ibid*), but not commonly used by the participating farmers in the PAR group. The winter moth can be controlled by applying a *B. thuringiensis* product. Since the moth is a very early season pest, PAR group farmers report that low temperatures often prevent efficient control.

1.2.4 Fourth phase of organic pest management

Apart from robust cultivars, the main strategy used by the PAR group farmers to control apple scab is frequent sulphur applications before, during and after rain according to a forecasting method. Pheromone dispensers for mating disruption are currently only available for the codling moth (SJV, 2015c). Since other tortricids cause more severe damage than codling moth, a strategy against all important tortricids must be developed to prevent damage and reduce pesticide applications (Tasin, pers. comm. 2015). Therefore our research group tested a multipheromone dispenser that was found to efficiently stop the reproduction of tortricids and keep damage levels low (Tasin et al., 2014; Porcel et al. 2015). There is ongoing work to support the implementation of this dispenser and associated trap and fruit damage monitoring. Monitoring and mass trapping of the apple fruit moth is being developed by our research group in collaboration with farmers and the Norwegian Institute of Bioeconomy Research (NIBIO) (Tasin et al., 2013; Knudsen & Tasin, 2015). Improved monitoring could facilitate oil application to control the pest (Lunde Knutsen *et al*., 2011). However, oils are not currently registered for use in Sweden (SJV, 2015c).

1.3 Participatory Action Research (PAR)

Participatory Action Research (PAR) is an action-orientated, interventionist and transdisciplinary approach to applied research which aspires to engage stakeholders in a process to bring about change and development (Reason & Bradbury, 2008). It strives to be a democratic, non hierarchical, sometimes bottom-up, approach whereby practitioners, researchers, advisors and other stakeholders engage in problem formulation, innovative design of strategies and systems, data collection and analysis, monitoring and evaluations (Chambers, 2008). Inquiry in PAR can include: 1) Taking actions to find solutions to a particular problem; 2) acquiring knowledge to design actions that will resolve a problematic situation; and/or 3) reflecting on previous actions so that they can be understood in new ways (Greenwood & Levin, 2007:63).

PAR has a rich historical origin since it emerged from many fields such as health care, community development, education, organisational management, agricultural and rural development, and has been underpinned by different scientific paradigms such as social constructivism, pragmatism and the transformative paradigm (Foote Whyte, 1991; Greenwood & Levin, 2007; Reason & Bradbury, 2008; Mertens, 2015). As such PAR is pluralistic and the use of theories and methods of inquiry, whether qualitative or quantitative, is guided by the needs of the problem situation as interpreted by the participants in the inquiry (Mertens, 2015; Chambers, 2008).

Although positivistic and postpositivistic research methods can be used as part of a PAR project, the qualitative research within which it is situated is based on a different ontology (how the world works – nature of reality) and epistemology (how we can learn about the world – nature of knowledge). This is a challenge not only for PAR, but also for the interdisciplinary research efforts for sustainable development in general. In order to work together on complex systems and achieve the expected synergies, we need to bridge the gap in understanding between scientific disciplines and between science and practice (experiential knowledge). With a background in postpositivistic natural science, I have struggled over the years to achieve this understanding myself. To help readers in a similar position, I provide a brief introduction to the strengths of PAR and how it differs from postpositivistic research traditions.

Within positivism and postpositivistic reductionist science, knowledge production is understood as the discovery of mechanistic laws (Harré, 1981). The ontological assumption is that the world is objectively given and commensurable. Hence the epistemological task is to apply objective methods of inquiry, randomised experiments where influencing factors are controlled and statistical analyses in order to obtain the probable truth (Guba & Lincoln 1994; Greenwood & Levin, 2007). If available tools are not developed to discover the mechanisms, e.g. tools to observe atoms or DNA, the aim is to discover patterns that reproduce in the same way under all circumstances (Harré, 1981). Gregor Mendel's experiment with peas showing how properties are inherited through generations, long before we had knowledge about genes, is a classic example.

Reductionist science is a powerful way to help us explain and understand many things. In the area of agriculture for example, it has achieved substantial increases in yields. However, the so called transfer of technology approach for agricultural research and extension based on reductionist science has proven inappropriate in many agricultural settings, since it has not sufficiently considered the complexity of local specific agricultural contexts (Foote Whyte, 1991; Reijintes et al., 1992; Pretty & Chambers 1993; Altieri, 1995; Röling, 2009). The motivation to use participatory approaches, including PAR, in agriculture is often described as emerging from the experiences of low farmer adoption rates of what was perceived as successful technologies by researchers, marginalisation of smallholders and unexpected environmental and health problems associated with the technologies (*ibid*).

Foote Whyte (1992) describes an experience which illustrates to why a participatory, systemic and action-orientated approach has been found to be a promising solution to such problems. The Institute for Agricultural Science and Technology (ICTA) in Guatemala designed a new training programme for agricultural professionals and technicians where they combined didactic instructions with field practice. Each trainee was assigned a farm plot which (s)he had to manage. The trainees used scientifically developed technologies and officially established recommendations, and the majority failed. Subsequent trainees learned to consult local farmers and achieved greater success. These professionals had now acquired the motivation and competence for PAR. There are countless such examples in the literature from across the world.

Over the past 50 years, agricultural research, development and extension work have increasingly come to view agricultural systems as operating wholes with complex interactions and effects (Röling, 2009). However, when we try to understand and change complex and interactive systems that are continuously changing (adaptive) due to internal and external influences the reductionism of the positivistic approach alone is not fit for purpose (Francis et al., 2013). Bawden (1991) and many others (e.g. Altieri, 1995; Vandermeer, 2008; Ison, 2009) call for systemic thinking to achieve sustainable livelihoods through farming. They argue that production technologies are interrelated with their biophysical and sociocultural environment and that solely studying individual details cannot reveal the emergent properties of a system, e.g an ecosystem, a farm, a healthcare system or a person when studied as a whole. Entities like these are context-specific (Bawden, 1991; Guba & Lincoln, 1994; Greenwood & Levin, 2007) and therefore not fully reproducible or comparable in space or in time (Greenwood & Levin, 2007). We can aim to strip them of their differences and find a sufficiently comparable common denominator, e.g. between farms, which may serve some purposes. However, doing so leaves a large part of reality unexplained and mysterious, hence decreasing its relevance and applicability (Guba & Lincoln, 1994).

With growing recognition of the role of humans in agricultural systems, social science approaches have come to play an increasing role in agricultural research and development (Foot Whyte 1991; Fieldstein & Jiggins 1994). This agrees with the ontological idea of coevolution in Agroecology (Altieri, 1995; Carporal & Azevedo, 2011; Vandermeer, 2011). Coevolution includes the human social system with its culture, values, visions of the world and social organisation as an evolutionary pressure on the rest of nature in each particular locale. Simultaneously, nature gives potential and limitations (short or long term) to the evolution and development of humans (Carporal & Azevedo, 2011). Several qualitative and systemic research paradigms, theories and methods are useful for this purpose.

For the purpose of understanding the perspectives and motives of other people, objectivity is seen as an unrealistic construct within many research paradigms, with the argument that our socio-historically inherited biases or prejudices are not external attributes that we can easily control, free ourselves from or set aside (Schwandt, 2000). In other words, philosophical hermeneutics and social contructivism assume that the world is only available to us subjectively and the epistemological challenge is to negotiate interpretations of this subjective world to achieve intersubjective understanding (Greenwood & Levin, 2007; Schwandt, 2000). Since in PAR the observer and the observed are co-dependent, or in a dialectical relation, the researcher becomes an active participant and balancing active involvement with integrity and open critical reflection replaces objectivity (Greenwood & Levin, 2007). Schwandt (2000) stresses that effective criticism of background assumptions requires the acknowledgment of knowledge as socially constructed.

As these research traditions understand qualitative research as a negotiation of interpretations, and knowledge as intersubjective rather than objective, the participation of stakeholders becomes a necessity (Groot & Maarleveld, 2000). Foote Whyte et al. (1991) and Carporal & Azevedo (2011) argue that the close collaboration between researchers and stakeholders and constant cross-checking of facts and negotiation of meaning employed in PAR assures an efficient learning or knowledge construction. The idea of objectivity as an impossible social construct and the acknowledgement of interactions between e.g. technology, biology, beliefs, values and societal structure in systemic thinking, leads to the conclusion that scientific innovation and technology cannot be neutral. Hence research must assume and take responsibility for its dialectical relationship with social norms, organisation and power relations (Chambers, 1995; Carporal & Azevedo, 2011, Schwandt, 2000). Consequently, comprehensive stakeholder participation in PAR and Agroecology is also a mean of democratising research (Chambers, 1995; Greenwood & Levin, 2007; Carporal & Azevedo, 2011).

Within the transformative paradigm, it is argued that social reality is shaped through history by social, political, cultural, economic, ethnic and gender factors (Mertens, 2015). These factors have constructed social structures that are limiting, confining or oppressive to some groups of people while they are beneficial to others (Guba & Lincoln, 1994). The epistemological challenge is to learn about these structures through studying their historical and cultural origin, dialectical dialogue and action (Guba & Lincoln, 1994). Kemmis & McTaggarts (2007) conclude that this insight give PAR practitioners clues on how, through action and critical reflection, they can release themselves from the constraints of social structures that are experienced as irrational, unproductive and unsatisfying, to themselves and others, and transform their intentions and practices. Although the structures are socially constructed, and not mechanistic laws, they do make a material difference to people (Denzin & Lincoln, 2011). Hence, there is a need for pluralistic methodologies of inquiry including both qualitative and quantitative methods, as subscribed to within the pragmatic paradigm (Denzin & Lincoln, 2011; Mertens, 2015).

In PAR, thought is not separated from action. Research and practice meet and subjectivity is explicitly acknowledged (Kolb, 1984; Checkland, 2000). We learn about complex systems, including feedback processes, conflicting purposes, varying perspectives, trade-offs and unexpected effects, by acting within the systems, reflecting on the impacts of those actions and using that knowledge to plan for new actions or changes. Hence PAR processes are designed to run as a series of iterative cycle of action, reflection and planning (*ibid*). An important feature in PAR is therefore the ability to be responsive to the situation, or in other words to learn and adapt during the research process. For these reasons, the starting point of a PAR intervention is to seek to improve a local problematic situation with a variety of stakeholders. According to Greenwood & Levin (2007:62), the "test of any theory is its capacity to resolve problems in real-life situations". The focus is to address the needs of specific contexts with their complexity, historicity and dynamism. Within that effort, scientific knowledge may be used together with experiential and local specific knowledge of farmers, where both complement each other (Greenwood & Levin, 2007; Carporal & Azevedo, 2011).

The strength of this approach is its ability to include all relevant aspects of a situation or system, since it increases knowledge about the complex interactions present and the relevance and applicability of innovative solutions. Whilst relevance is the strength of PAR, a trade-off is the limitation of replicability, and hence there is a need to treat the created knowledge carefully and flexibly when transferring it to other settings (Dick, 1993).

Generalisability in PAR is not understood as universal context-free knowledge (Greenwood & Levin, 2007). Instead, knowledge is adapted between situations by understanding their contextual factors and making a critical assessment of whether the processes and structures have enough in common to make it worth-while linking them (*ibid*). Evaluation criteria for PAR research vary and partly depend to which scientific paradigm the researcher subscribes (Plack, 2005), and to collaboratively defined criteria. However, common features of good PAR research include using multiple methods to arrive at conclusions (Dick, 1993), stakeholder willingness to accept and act on collectively produced results, and collective evaluations of whether suggested solutions and actions taken helped solve the problem (Greenwood & Levin, 2007).

According to Greenwood & Levin (2007), PAR acknowledges that each situation is created by specific historical and organisational conditions and could have turned out differently under different circumstances. The role of theory in PAR is therefore not to predict the future. Instead, theory helps to explain why things happened, how things are structured and organised in order to suggest possible future scenarios and give good reasons for probable next outcomes supported by other cases and contexts in a coherent way.

Researchers in PAR projects which situate themselves within pure constructivist or positivistic paradigms are less inclined to hold the view that methodologies and tools belonging to different ontological and epistemological beliefs can be mixed (Denzin & Lincoln, 2011). PAR projects guided by the pragmatic and transformative paradigms (e.g. critical theory) are able to welcome multiple beliefs and methods (e.g. experiential knowledge, qualitative and quantitative methods) as contributions that are interpreted through local action and participatory dialectical and critical dialogue (Greenwood & Levin, 2007; Kemmis & McTaggart, 2007; Mertens, 2015).

1.4 Cultural historical activity theory (CHAT)

Cultural Historical Activity Theory (CHAT) and expansive learning are theories proposed by Engeström (1987) in order to understand and bring about development. Below I introduce the theory and methodology of CHAT.

Engeström (1987) stresses that in CHAT, the activity system triangle (Figure 1.4.1) is taken as the smallest unit of analysis which includes "the whole", meaning its basic, elements and internal relations (structure), its origin and the internal developmental driving force.

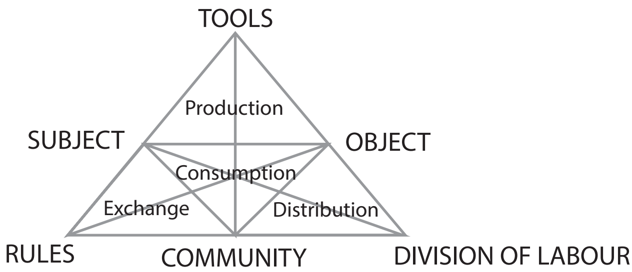

Figure 1.4.1. Activity system triangle including subject, object, community and the mediating cultural artefacts tools, rules and division of labour according to Engeström (1987:78).

This activity system can be seen as interacting with other activity systems in a network by feeding inputs into each other (Figure 1.4.2) or by collaborating toward a common object and motive.

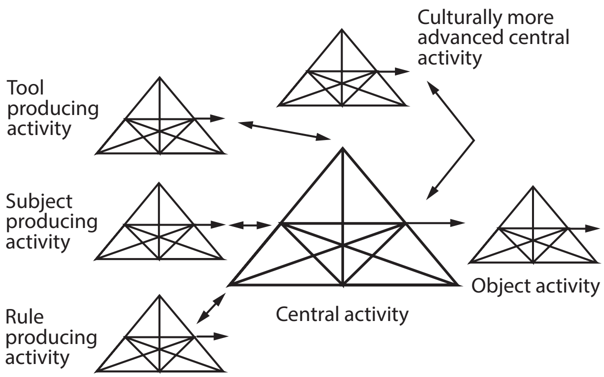

Figure 1.4.2. Network of functionally interdependent activities with neighbouring activities related to a central activity system (Engeström 1987:89).

Associated with the activity system and networks with their internal developmental driving force is the theory of expansive learning. Expansive learning occurs in iterative cycles with several steps which are based on the CHAT theory of internal developmental driving force and the nature of knowledge creation. Below I explain why the activity system is seen as the smallest unit of analysis and how the steps of the expansive learning cycle are motivated.

The internal developmental driving force is explained as historically accumulating tensions or internal contradictions which are not directly visible in the activity system triangle. The way they are commonly pictured is as lightings within or between elements of one activity system or between activity systems (not shown in Figure 1.4.1-2). The activity system must be imagined as mobile through time and remoulded by the successive development of four contradiction levels. This is elaborated by Engeström (1987) and Engeström & Sannino (2010) to the theory of expansive learning which is illustrated by an iterative cycle with five phases (Figure 1.4.3).

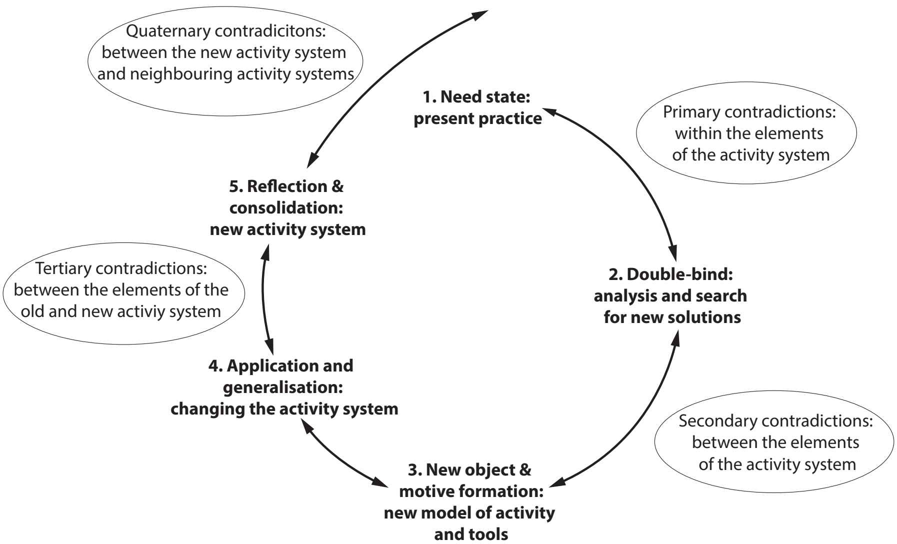

Figure 1.4.3. Ideal model of the expansive learning cycle (Engeström & Sannino, 2010).

Before I explain the theoretical underpinning of CHAT, I present an example of an imagined activity system of language education. This activity system can include a teacher as a subject, and student learning as an object. The learning of the language is mediated through tools as a computer, exercises, dictionary, grammatical structure etc. Rules will mediate, how education should be performed, between the teachers and others involved in language education. A division of labour will mediate how the different tasks should be divided between those involved in language education. The societal division of labour can be within the activity or between different activities in a network of activity systems which interact (Engeström, 1987). An example of a network could be an administration activity producing rules for the central education activity and another activity producing textbooks for language education. Engeström (2001) also suggests that objects may be partially shared between different activities that collaborate to achieve the objects.

The tools, rules and division of labour will be shaped by how they developed through history in the particular context and therefore language education will differ at different times and in different places (Engeström, 1987; Levant, 2012). This development is driven by internal contradictions which, since they are historically accumulated structural tensions, cannot be observed directly. Instead they are manifested as disturbances, dilemmas, ruptures, conflicts and innovations in a particular current activity system (Pereira Querol, 2011). Contradictions, their manifestations and the expansive learning cycle are explained in more detail in Paper I and only briefly described here based on Engeström (1987) and imagined examples from farming activity.

The original contradictions are the primary contradictions while the later levels are manifestation of these primary contradictions. Primary contradictions in a capitalist mode of production exist between the use-value and the exchange-value within any of the elements of the activity system. For example the use value of a pesticide is to control pests in agriculture. A pesticide company may wish to help farmers, but their production is dependent on the exchange value and hence a persistent perceived need to buy pesticides.

Primary contradictions develop into secondary contradictions between elements of the activity system. The pesticides may kill natural enemies of the pests creating secondary pest outbreaks that the pesticides cannot control, and therefore the object of high productivity cannot be achieved. This is the point when participants in an activity start mobilising to make a change in order to resolve the contradictions.

If the disturbance is sufficiently severe, a new object and motive are formulated in the third phase of expansive learning and starts to be implemented in the fourth phase. The farmers may decide to convert to organic farming, use robust cultivars and support natural enemies of the pests by improving the habitat of these on the farm. At this point tertiary contradictions emerge between elements of the new and old activity system. For example the new activity may be more costly due to higher labour demand, which contradicts the object of economical sustainability. By inventing an organic label, the added value can be communicated and a higher price for the products can pay for the increased labour. Alternatively, farmers can be recompensed for the common goods they produce by the state.

In the fifth phase the new activity is consolidating and becoming more general in society. This is when quaternary contradictions emerge between the new activity and other activities in society, for example debates or conflicts between organic farmers and pesticide companies.

Virkkunen and Shelley Newnham (2013) summarise the theoretical underpinning of CHAT as follows. Within CHAT, it is believed that material things have a physical existence outside the human mind. However, things are only moments in a process of interactive development between the things and their environment that mutually change each other through history (dialectical). In each single moment, the thing is a result of a particular structure within which it exists and how the relationships within that structure have been organised through history. However, human interaction with the environment and other humans is not biologically determined in a fixed way. Instead, it is created in a continuous interactive process with the environment.

CHAT as proposed by Engeström (1987:38-39) was his response to a lack of "coherent theoretical instruments for grasping and bringing about processes" which includes the view that people are not only a product of evolution and assimilate culture, but that they create and transform their reality and, while doing so, learn and change themselves. This ontological and epistemological view draws on the work of cultural-historical psychologists such as Vygotsky and Leont'ev (Engeström 1987), and the related interpretation of historical materialism and dialectical materialism by philosophers such as Il'enkov and Davydov (Levant, 2012). According to Levant (2012) Il'enkov explains that the ideal (non-material phenomena as thoughts, laws, customs, concepts, moral imperatives etc.) is not simply something that exists in the human mind (the constructivist view), and it is not a mere individual physiological reflection of material objects in our brains (positivistic view). Rather, it is created during interaction with the material world within a culture or society. We learn to give meaning to the material things we use by the cultural and societal context in which we develop and then transform these ideas to activities, which is called materialisation, objectification (Levant 2012) or externalisation (Engeström, 1987). Therefore our ideas have an objective (material) existence outside ourselves in the processes of our activities, which have an effect on material objects, including ourselves.

Levant (2012) continues by illustrating this with the example of the value we give to a commodity. The value is not the same as the material properties of the commodity, but it exists in our cultural interactions and it materialises or becomes objectified in our labour, which defines the value. I suggest that in the context of organic farming, it can perhaps be understood as the principles of organic farming objectified in an ecological label. The organic principles cannot be seen in the label or product, and instead the product and label represent the materialisation of the organic principles, such as the production process and its effects on e.g. workers (fair working conditions) and the environment (ecological sustainability). In this sense the ideal has an objective existence in the human transformation of the material world, which is a dialectical process of creating cultural meaning for things that in turn informs our activities, which change the things (Levant, 2014).

Engeström's contribution to this school of thought was the development of a concept of object-orientated activity, which is mediated by technical and psychological tools as well as by other human beings, as the smallest unit of analysis for understanding human change and development (Engeström 1987; Virkkunen and Shelley Newnham, 2013).

The development of the activity system model began with Vygotsky's model of mediated act (Vygotsky, 1978, 74) which was needed to explain the birth of higher psychological functions in humans and connected individuals to their culture through the signs they use to control their response to environmental stimuli. The tripartite model (subject, object, tool) was still at the level of individual actions, but it suffered from the problem that their ultimate motivation is seldom visible without looking at the wider context where the actions take place and are embedded (Engeström, 1987; Miettinen, 2001; Virkkunen and Schaupp, 2011). This problem was addressed by Leont'ev (1981) using the example of hunting. An individual hunter's action, such as beating the ground to scare the game animals away, seems absurd (he scares the prey away and does not get anything to eat) unless seen in a wider context: he scares the animals away to herd them to a place where other hunters can kill them, and he gets his share through his action that connects with the wider, collective activity of hunting through division of labour (Leonty'v, 1981). In 1987, Engeström produced a full model that graphically superseded Vygotsky's tripartite model and Leont'ev's joint activity models, resulting in a general model of human activity, showing how the relationship of human beings (subjects) with their environment (object) and with other human beings (community) evolved over time and came to be mediated by tools, rules, and the division of labour. Both individual and societal development can be understood as a significant and long-term qualitative change in the way humans relate to the world through a remediation of activities (Engeström, 2005, 41).

Virkkunen & Shelley Newnham (2013) describe the basic idea that subjects (individual humans or groups e.g. an association) have needs that they fulfil by performing activities which means interacting with objects and other people in the world. Activities can therefore be understood as a set of actions directed towards transforming an object in order to fulfil a need (Engeström, 1987). The notion of object in CHAT is perhaps not intuitive and requires more explanation. Miettinen (2005) explains that an object of an activity includes a collective motive and "cannot be understood as a unitary, distinct thing or and easily definable entity. Rather, it is an assembly of material entities embedded in economic and social relationships". Miettinen then describes how an object and motive come into being when things are not working in a satisfactory manner, which creates a need state. When an object which address this need is encountered or created, the need becomes the motive for the object. This view of the object corresponds to Il'enkovs interpretation of the relationship between the ideal (non-material phenomenon) and the material world through activity (Levant, 2012) as described above. Objectively here refers to culturally and socially defined meaning created through engagement in collective activity. When this meaning is acted upon (externalised) in activities it has an impact on people and things (Levant, 2012; Virkkunen & Shelley Newnham, 2013).

The fact that the object of the activity has an agreed meaning on a societal level does not, however, deny that each person within an activity will have their own personal sense of the activity and object (Virkkunen & Shelley Newnham, 2013). Engeström (2001b) expresses this as the multi-voicedness of an activity, meaning that people carry multiple points of view, traditions and interests. As an activity develops, some people start to deviate from the established norms which is one kind of trigger for an expansive transformation of the activity, widening its scope of possibilities as the object and motive change (*ibid*). Engeström (2001a) calls this a Zone of Proximal Development (ZPD), which can be seen as a collective journey from the position of individuals with their personal sense, and the actions they take based on that, towards a new form of societal activity (with new object and motive), which is generated collectively to address disturbances experienced in the old activity.

Engeström (1987) emphasises the importance of working out a Zone of Proximal Development (ZPD) in order to guide the development of the activity over time. This zone has two meanings according to Virkkunen & Schaupp (2011). They describe the first meaning of the ZPD as its representational aspect in the form of a "model of the systemic causes of current problems and the possible new form of the activity". Engeström (2001:157) describes it as follows;

> "The zone of proximal development may be depicted as a grey area between actions embedded in the current activity with its historical roots and contradictions, the foreseeable activity in which the contradictions are

> expansively resolved, and the foreseeable activity in which the contradictions have led to contraction and destruction of opportunities" (Engeström, 1987:157).

The second meaning of the ZPD is its processual aspect, described by Engeström (198:147) as;

> "the distance between the present everyday actions of the individuals and the historically new form of the societal activity that can be collectively generated as a solution to the double bind potentially embedded in the everyday actions". According to Virkkunen & Schaupp (2011), this aspect of the ZPD "can be understood as the mastery of appropriate actions for reaching such generalisation [the representational aspect of ZPD] and using the generalisation in developing the activity". This is related to Vygotsky's and Leont'ev's understanding of knowledge construction as mediated by signs, tools and other people in our cultural-historical context (Virkkunen & Schaupp, 2011). Hence it is a collaborative or social endeavour occurring when we interact with things and people in our environment.

I interpret this as a set of the current and possible activity systems in which some fulfil the collectively foreseeable future or the object and motive, while others do not. Any model of future activity that does not address and solve those contradictions will eventually turn out to be non-expansive (Engeström, 2005). This ZPD can be used to interpret where the current actions are situated and which collaboratively planned learning actions may lead towards the future activity aimed at resolving current contradictions. A step in the collective creation of a foreseeable future and ZPD is to understand the historical roots of the activity as it is today.

Learning, and therefore also development because it assumes learning as its predecessor, can be interpreted as the production and application of production-relevant generalisations (Pihlaja, 2005). In CHAT, generalisations have a central role because expansive learning is based on the dialectics of ascending from the abstract (generalisations) to the concrete (specific activity) and back (Engeström, 1999). In CHAT, generalisations are not only made empirically by controlling variables and replications conducted to study a phenomenon. The need for another kind of generalisation comes from the fact that phenomena are constantly changing. According to Davydov (1990) the methodological challenge of this theoretical generalisation is oriented towards revealing the logic of development, the genetic roots of a phenomenon and the system of functional relationships determined in its occurrence and development. Il'enkov (1977, see Pihlaja, 2005) explains this kind of generalisation as not only looking for the common, directly observable attributes of the phenomena, but also for their common ancestor. The ancestor can be thought of as the first case or model in which a historical contradiction has been solved and it shows the general principle of the systemic connections of the phenomenon. This ancestor or origin often continues to exist as one case among many others, which are its offspring. The generalisation also includes an understanding of the process that leads to the structure of the generalised phenomena. According to Leont'ev (1933, see Pihlaja 2005) a general phenomenon is differentiated from another phenomena both by its material attributes and the process by which it came into being.

2 Objectives

The overall objective of this thesis was to support the development of pest management in organic apple production towards socially and ecologically sustainable use of resources that would be feasible and profitable for the farmers. To achieve this, we explored the possibility of expanding the knowledge production system to become a collaborative interdisciplinary activity between farmers, advisors and researchers. The purpose was to establish direct relations in order to address the contradictions in organic pest management in apple production by combining farmers' experiential knowledge, PAR methodology, CHAT, on-farm observational trials, and scientific field and laboratory experiments.

My personal objective was to make us of and expand my horticultural competence based mainly on natural science to include social science and broader and deeper understanding of current farming challenges. This would create a wider and more comprehensive research platform, which will deliver useful results moving development in the direction towards sustainable farming.

As the PAR process progressed a need emerged to find a theory and tools which could support participatory problem formulation by the identification of the historical root causes to experienced pest problems, and explain the main drivers behind their development. We assumed that if the root causes of pest management problems on the five farms included in the study could be identified and addressed, instead of their symptoms, it would help us to develop more sustainable solutions. We were interested in whether the PAR methodology and process contributed to the farmers' progress in developing their pest management and whether CHAT, with its analytical tools, could give new insights into our PAR process, particularly on the appropriateness of its problem-formulating phase. By connecting the PAR case process in organic apple production with developments in agriculture in general and organic farming in particular, three research questions were formulated and answered in paper I:

1. What insights can CHAT and its analytical tools offer to our PAR group?
2. What are the historical dimensions of organic farming in Sweden?
3. How has the development of historical contradictions shaped organic farming?
4. What are the historical roots and systemic properties of the current disturbances in intensive organic apple production?

As the apple sawfly was identified by many farmers and the apple advisor as one of the most severe pests in organic farming and with the least research attention, we performed two studies on possible control measures: 1) A forecasting method combined with application of the botanical pesticide Quassia amara; and 2) use of entomopathogenic fungi against the soil dwelling phase of the apple sawfly. Specific objects of the first study (paper II) were:

5. To assess whether the first trap catch of apple sawfly in Sweden could be predicted by an air-based temperature sum model and used to indicate optimal timing of trap placement for monitoring or mass trapping.
6. To observe whether trap catches of sawflies decrease because of visual competition from the apple flowers during bloom.
7. To investigate whether apple tree phenology would co-vary with observed egg and larval stages.
8. To assess whether the efficacy of *Q. amara* treatment differs depending on time of application at: i) petal fall, ii) according to trap catches and temperature sums, or iii) at observed egg hatch under Swedish conditions.

The objectives of the second study (paper III) were:

9. To assess the effect of a commercial strain of *Beauveria bassiana* (Balsamo) Vuillemin and an isolate of the most common indigenous entomopathogenic fungal species in orchard soil against apple sawfly larvae under laboratory conditions.
10. To study relative apple sawfly mortality and mycosis after soil application of a commercial *B. bassiana* product.
11. To evaluate persistence of the commercial *B. bassiana* product.

3 The Participatory Action Research approach of this study

3.1 Theoretical positioning and choice of methodology

The participatory action research (PAR) approach adopted in this thesis is perhaps closest to the pragmatic paradigm described by Mertens (2015) which allows the use of mixed methods depending on the needs of the situation and the research question. The transformative paradigm (Merten, 2015) may partly apply in the sense that the overall intention of the PAR project described in this thesis was to contribute to the development of ecologically sustainable and socially just food production, and give a voice to the stakeholders most closely affected by agricultural research by including them into the research process. Furthermore, for the retrospective analysis after the intervention, Cultural Historical Activity Theory (CHAT) was applied with the purpose of unveiling the historically accumulated contradictions that have shaped the current structures and perceived problems in organic farming.

In this collaborative endeavour, both qualitative and quantitative methods and data were employed. Field and laboratory trials assessing control measures for the apple sawfly were performed according to a postpositivistic methodology and resulted in Papers II and III. However, this methodology was situated within a broader qualitative framework where problem formulation, innovative design of strategies and systems, data collection and evaluations were performed collaboratively within the intersubjective and action-orientated epistemology presented in Paper I.

The intervention was designed according to iterative learning cycles where the on-farm practices were discussed and compared within the group, and scientific literature and our scientific experiments. This prompted changes in practices, which were further reflected in a new cycle.

Cultural Historical Activity Theory (CHAT) was introduced at a later stage of the project as a solution to the need of a theory of change and methods to suggest the historical and structural root causes of the problems experienced by growers in organic pest management in apple production. The assumption was that if problems could be traced to their historical and structural roots and supported by a theoretical framework for understanding and analysing the drivers of development, it would be possible to develop more sustainable and resilient pest management activity.

The constant tension between high ecological sustainability and economic viability that the group experienced during the inquiry seemed to be addressed by the idea of the inherent contradiction between use-value and exchange value proposed as the motor of development in CHAT. Its historical analysis approach, connecting contradictions with their current manifestations and the current structure of the activity as a basis for designing new activity systems appeared to address the assumption that by understanding and targeting root causes it would be possible to develop more sustainable food production.

Comparing CHAT with PAR, there appears to be ample common ground. CHAT acknowledges action as a source of knowledge and the inclusion of stakeholders through its idea of multi-voicedness in activity. I chose to investigate whether CHAT could offer insights to the PAR project because it offered potentially interesting theories and tools to make coherent historical analyses, problem formulations, designing future scenarios and evaluation of workability. The focus in CHAT on the whole activity system and not only individual experiences fitted with the aspiration to perform a systemic research inquiry and to the explicit wish of the participants to be subjects and not become objects of study.

3.2 Participants

The project described in this thesis was initiated by pest management researchers together with the Swedish apple growers' association, Äppelriket. A PAR group was formed with the following composition and competence: i) Two advisory officers from Äppelriket and all five farms with intensive organic apple production within the association at that time, which were included on the advisors' recommendation. These farms are described later, in the section on theory-historical analysis; ii) senior researchers and a project leader with long experience within organic and integrated horticultural production and PAR. One senior researcher was an experienced apple grower and pheromone scientist; iii) and I was a PhD student with previous horticultural education with a specialisation in participatory systemic action research and agroecology; iv) an advisor and process facilitator experienced in participatory research and development within horticultural crops from the Regional Board in Västmanland; and v) other researchers (working with forecasting and natural enemies), students and the president of Äppelriket, who were invited to participate in the group sessions according to the needs of the group.

3.3 Research process

During the three-year PAR study, interviews and 10 recorded and transcribed group sessions were held (Table 3.3.1 & Paper I) to discuss field trial planning, result presentation and evaluation, and current pest management problems and possible solutions in iterative annual cycles. Each meeting followed and iterative PAR cycle. Suggestions for meeting topics were collected before hand and at the end of each meeting it was evaluated if the topics had been addressed. Ideas on how to address the identified problems were collected in an idea bank during all meetings. The idea bank was developed into an action plan where a time frame was set for each action, stating if it should be performed in the following cropping season, during the course of the project or in the future. Actors with potential to contribute to the actions were suggested both from within and outside the group. When actions fell outside the project time, the group looked for other actors who could take them on. The group was learning and innovating both pest management strategies and how to collaborate with the different competences and objects within a group. The trials and the work process in the group were continuously evaluated. Three field walks were organised with the objectives of observing the ongoing field trials and learning how to correctly identify apple flowering stages, pests and natural enemies.

The scientific field trials planned, performed and/or evaluated by the participants of the group related to: use of entomopathogenic fungi against apple sawfly (*Hoplocampa testudinea*) (Paper III); forecasting and control of apple sawfly with the botanical pesticide *Quassia amara* (Neupane, 2012; Paper II); and monitoring and control of tortricid pests and the apple fruit moth using pheromones and kairomones (Tasin et al., 2014; Knudsen & Tasin, 2015; Porcel et al. 2015). Observational trials were performed with flowering strips in two of the orchards. Two of the researchers visited Danish growers experienced in biodiversity management for pest control. A popular scientific article was written to describe their experiences and was presented and discussed within the group.

In addition, four annual apple stakeholder workshops were organised in 2010-2013 with approximately 50-60 participants (Table 3.3.1). An additional workshop was organised in collaboration with EPOK (Centre for Organic Food and Farming) in 2015 on the theme of how biodiversity can enhance pest management in apple production. Researchers within different fields of apple research and advisors were invited to present and discuss their work together with apple growers, Swedish Board of Agriculture officials and pest management companies. During the second session of the stakeholder meetings, the participants were divided into working groups according to themes suggested by them. Group works were facilitated to arrive at concrete suggestions for future research and development. Whenever possible, ideas from the workshops were incorporated into the ongoing project, student projects or new research project applications. At each new annual workshop, a follow-up study was made and actions taken based on previous workshop suggestions were presented to ensure continuity between the workshops (iterative learning), and to promote continued participation by the stakeholders.

Table 3.3.1. Intervention events and methods, including the type of information obtained and the stakeholders involved

Method	Type of information	Date	Stakeholders
Annual stakeholder seminar and workshop	Presentation and discussion of ongoing apple research, workshop on future research and development. Seminar and workshop notes	2011.02.10	54 participants. Apple growers, advisors and researchers agricultural board representatives, pest management companies
First PAR group meeting	Project presentation and expectations of participants, planning field trials. Meeting notes	2011.02.21	Five participating farms, apple association advisor, researcher, PhD student, facilitator
Survey + Follow-up interview	General facts about farms, grading of major production challenges, pest & disease problems, written survey and interview notes	Spring 2011, start of the project	Five participating farms, PhD student
Second PAR group meeting	Presentation and discussion of field trials and farmers' pest management issues this season. Recorded meeting and transcripts	2011.08.25	Three participating farms, apple association advisor, researcher, PhD student, Master's student, facilitator,
Farm interviews	Farm background and facts, resource flows, pest management problems with special focus on apple sawfly	Autumn 2011	Five participating farms, PhD student, Master's student
Third PAR group meeting	Presentation of new pheromone and kairomone project, evaluation of monitoring and flower strip activities, evaluation of learnings, action plan.	2011.12.15	Four participating farms, apple association advisor, researcher, PhD student, facilitator

Annual stakeholder seminar and workshop	Presentation and discussion of ongoing apple research, workshop on future research and development. Seminar and workshop notes.	2012.02.09	60 participants. Apple growers, advisors, researchers, agricultural board representatives, pest management companies
Fourth PAR group meeting	Discussion about collaboration methodology and project objects, research result discussion, planning field work and learning actions.	2012.03.13	Three participating farms, apple association advisor, two researchers, two PhD students, Master's student, facilitator
Fifth PAR group meeting	Learning activity, identifying flowering stages in apple, collecting and identifying pests and beneficial organisms at one of the participating farms.	2012.05.08	Four participating farms, three researchers, PhD student
Annual stakeholder seminar and workshop	Presentation and discussion of ongoing apple research, workshop on future research and development. Seminar and workshop notes.	2013.01.21	51 participants. Apple growers, advisors, researchers, agricultural board representatives, pest management companies
Sixth PAR group meeting	Discussion of pest management issues in previous season, conceptual model of pest management in apples, update of action plan, learning action: identification of phenological stages of natural enemies and their biology	2013.01.22	Four participating farms (five growers), researcher, PhD student
Seventh PAR group meeting	Learning activity: collection and identification of flowering stages, pests and natural enemies, model of pest phenological stages and control options over the season, discussion of organic farmers' needs of development in tools, knowledge and rules.	2013.05.23	Two participating farms (three farmers), MD of apple association, advisor, two researchers, PhD student
Pest manageme nt course	Organised by Swedish Board of Agriculture to present and discuss ongoing research.	2013.12.18	77 participants. Apple growers, advisors and researchers agricultural board representatives, pest management companies
Eight PAR group meeting	Discussion of pest management issues in the previous season	2013.12.18	Five participating farms, three researchers, PhD student, facilitator
Survey	Follow-up of the survey at the start of the project	Spring 2013	Five participating farms, PhD student
Ninth PAR group meeting	Short presentation of organic farming objects through history, activity triangle, feedback on summary of primary and secondary contradictions and their manifestations through the project	2014.01.31	Three participating farms, apple association VD, advisor, three researchers, PhD student, facilitator

Tenth PAR group meeting	Final meeting. Continuation of feedback on summary of primary and secondary contradictions and their manifestations through the project, discussion on desired developmental direction and the role of the project, evaluation of learning and collaborative methodology.	2014.03.11	Five participating farms, advisor, two researchers, PhD student, facilitator
Organic fruit seminar and workshop	Invitation to present and discuss ongoing research and facilitate workshop on how biodiversity can be used to enhance natural biological control in apple orchards.	2015.04.21	Apple growers, advisors, researchers, agricultural board representatives,

4 Organisms studied

4.1 Arthropod pest *Hoplocampa testudinea*

The apple sawfly, *Hoplocampa testudinea* Klug (Hymenoptera: Tenthredinidae) (Figure 4.1.1), is an important univoltine pest of apples in Europe and North America (Pyenson, 1943; Vincent & Mailloux, 1988; Cross et al., 1999). The sawfly hibernates in the soil as pre-pupae and emerges in the flowering period of apple to oviposit in the flower calyx (Miles, 1932; Graf et al., 2001; Ciglar & Baríc, 2002). Accordingly, there is a link between the reproductive period of the apple sawfly and the phenological flowering stage of apple trees, which can be described by the BBCH[1] scale (Meier et al., 1994) and used to time control measures against the pest. The damage caused by the hatched sawfly larvae comprises superficial tunnelling under the fruitlet skin and direct radial entry into the fruitlet and feeding on the kernel (Miles, 1932; Dicker & Briggs, 1953). In the Netherlands, sawfly populations double every year if no control measures are undertaken (Zijp & Blommers, 2002). Apple sawflies are known to be controlled by natural enemies, i.e. parasitoids, nematodes and entomopathogenic fungi (Jaworska, 1992; Babendreier, 1996). Apple sawfly

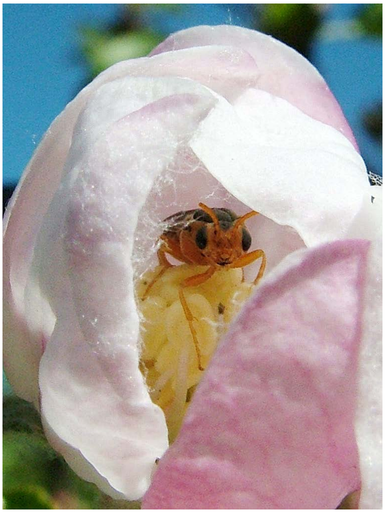

Figure 4.1.1. Adult apple sawfly in apple flower. Photo: Bela Molnár

[1] BBCH = Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie.

control in Swedish conventional orchards relies on the use of non-selective synthetic insecticides at the time of egg hatch (Manduric, 2014; Paper II), while control in European organic orchards commonly relies on use of a commercial or homemade extract from the shrub *Quassia amara* L. (Simaroubaceae) (Ascard & Juhlin, 2011). Another control opportunity, with soil application of entomopathogenic fungi (EPF) or nematodes, appears at the time of larval descent to the soil for hibernation. Jaworska (1979, 1981) demonstrated high apple sawfly mortality in laboratory and semi-field trials with the fungal species *Metarhizium anisopliae sensu lato (s.l.)*, *Beauveria bassiana s.l.*, *Isaria farinosa* (Holmsk.), *Isaria fumosorosea* (Wize.), *Aspergillus flavus* Link and *Lecanicillium lecanii* (Zimm.) (all Ascomycota: Hypocreales).

4.2 Biological control effect and soil persistence of the entomopathogenic fungus *Beauveria bassiana*

Beauveria bassiana (Balsamo) Vuillemin is an entomopathogenic fungus (EPF) with a wide host range including *H. testudinea* (Jaworska, 1981). However, most isolates of this fungus have a more restricted host range (Zimmermann, 2007). Although *B. bassiana* occurs on insect cadavers both below- and aboveground (Meyling et al., 2011) (Figure 4.2.1), free-living conidia are highly sensitive to UV-light and infection requires a humid environment (Zimmermann, 2007). The average temperature optimum for germination and infection is 23-28 °C (minimum 5-10 °C, maximum 30-38 °C) (*ibid*). There is a slow decrease in conidial germination and mycelial growth approaching 15-18 °C and a subsequent rapid decrease to the minimum temperature. However, Jaworska (1981) showed high sawfly mortality due to *B. bassiana s.l.* mycosis at 17.3 °C soil temperature.

Figure 2.2.1. Sporulating Beauveria bassiana covering infected apple sawfly larvae. Photo: Weronika Świergiel.

Another factor that influences EPF efficacy is humidity (Jaworska, 1981; Jaronski, 2007). Gaugler et al. (1989) found that a high level of Colorado potato beetle (*Leptinotarsa decemlineata* (Say)) mycosis only occurred after soil irrigation. However, studies on the impact of soil moisture on conidia viability and mycosis have produced contradictory results (Lingg & Donaldson, 1981; Studdert & Kaya, 1990; Hallsworth & Magan, 1995; Lanza et al., 2009; Cossentine et al., 2010). Studdert & Kaya (1990) showed a significant increase in *Spodoptera exigua* (Hübner) pupal mycosis by *B. bassiana* (strain ABG 6178) at a water potential of -37 to -200 bar compared with -0.3 to -15 bar. In contrast, Garrido-Jurado et al. (2011) reported maximum mycosis by two strains of *B. bassiana s.l.* in the Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann)) at a water potential optimum of -2.8 to -4.7 bar, well over the permanent wilting point of -15 bar. Those authors also showed varying effects depending on fungal strain.

Fungistatic effects caused by either antibiosis or pesticides such as sulphur (commonly used organic fungicide) have been shown in laboratory studies (e.g. Lingg & Donaldson, 1981; Sterk, 1993; Shah et al., 2009; Demirci & Denizhan, 2010;) and are correlated to low EPF levels in the field (Jabbour & Barbercheck, 2009). However, it appears that single applications of sulphur do not result in a decrease in insect mortality (e.g. Saito & Yabuta, 1996; Shah et al., 2009; Demirci et al., 2011). To the best of my knowledge, no previous study has investigated the fungistatic impact on EPF of the accumulation of several annual sulphur applications in a field situation.

Mechanical weeding is common practice in intensively managed organic orchards and could affect the persistence of a fungal biocontrol agent, since tillage has been shown to have a detrimental effect on EPF (Bing & Lewis, 1993; Sosa-Gomez & Moscardi, 1994; Hummel et al., 2002). Several studies have reported a higher negative effect of cultivated soils compared with natural habitats on occurrence of *Beauveria* spp. than on *Metarhizium* spp. (e.g. Vänninen, 1996; Quesada-Moraga et al., 2007; Medo & Cagan, 2011). However, previous studies indicate that short-term persistence of *B. bassiana* is not strongly influenced by limited tillage for formulated products (Storey et al., 1989; Gaugler et al., 1989). In addition, Shapiro-Ilan *et al.* (2008) found no significant difference in mortality or mycosis in pecan weevils with or without soil incorporation of *B. bassiana*.

The rapid reduction in *B. bassiana* density in cultivated soils is an advantage, since it decreases the risk of infecting non-target organisms. However, as Scheepmaker and Butt (2010) have pointed out, no reference is available for the time within which the concentrations should return to the background level. Those authors suggest a reference background level of 830 CFU/g soil, defined as the 95th percentile of the geometric mean, representing the upper natural background level in other published studies.

Beauveria bassiana density reductions post application are normally fast, with a majority of the spores disappearing after a few days to weeks, while depending on the dose of application and local conditions the density may return to background levels after 6 months or remain elevated after a year (Inglis et al., 1997; Storey et al., 1989; Müller-Kögler & Zimmermann, 1986).

5 Paper I: An Activity-Theoretical view on pest management development in apple production within a Participatory Action Research project.

This paper offers a retrospective view on pest management development in Swedish organic apple production within a Participatory Action Research (PAR) project using Cultural Historical Activity Theory (CHAT) as an analytical lens. As the project progressed a need emerged to find a theory and tools which could support participatory problem formulation by the identification of the historical root causes to experienced pest problems and explain the main drivers behind their development. Cultural Historical Activity Theory (CHAT) offers an explicit theory of change to analyse how the activity came to be and why it has the problems that need resolving (Engeström, 1987). This means that it can help in recognising the places of innovation in the activity and thereby inform about solutions to the problems at the system level. It was assumed in this thesis that if the root causes of pest management problems on the five farms included in the study were identified and addressed, instead of their symptoms, the solutions would be more sustainable. My main interest was in whether the PAR methodology and process contributed to the farmers' progress in developing their pest management and whether CHAT, with its analytical tools, could give new insights into our PAR process, particularly on the appropriateness of its problem-formulating phase. The CHAT analysis was performed retrospectively, in collaboration with researchers more experienced with CHAT. The theory was thus not used for planning or executing the PAR process, but for evaluating it.

5.1 Materials and methods

In order to answer the research questions proposed in Paper I, a methodology called Developmental Work Research (DWR) was partly applied (Engeström, 1987, 2005). DWR is an interventionist methodology, based on Activity Theory principles and concepts, originally created as a tool to study and induce expansive learning (Figure 1.4.3, chapter 1).

In Paper I the focus was on the second phase of the methodology: analysis of the activity. The aim of this phase is to produce inside information in order to resolve contradictions in the activity. Three analyses were conducted: theory-historical analysis, object-historical analysis and actual-empirical analysis. The following paragraphs explain how these methods were applied in Paper I.

Based on Activity Theory, in order to understand problems experienced by the farmers, it was necessary to find their historical origins by tracing changes in the role and function of agriculture. By comparing the reasons behind historical farming concepts and their structure in the theory-historical analysis, the intention was to develop a hypothesis on the developmental dimensions within which previous solutions to problems have been found. In the following step, the historical development was analysed with the theory of contradictions and developmental cycles in with the object-historical analysis. Primary contradiction was the theoretical concept of the root problem sought and the developmental cycle was taken as the theory of the process through which these primary contradictions evolve and finally manifest themselves as the problems experienced by the PAR farmers. In the final actual-empirical analysis, the theory of contradiction manifestations showed how to identify symptoms or manifestations of these contradictions in the current situation.

5.2 Results and discussion

5.2.1 Theory- and object-historical analysis of Swedish farming leading to intensive organic farming and beyond

The new land acquisition rules relating to the rational productivist policy of the Swedish state favoured land concentration, high labour productivity, specialisation and large-scale production (Domeij, 1995). At that time the prices paid to farmers for the main agricultural products were negotiated with the state and based on production costs using the prescribed rationalisation tools (Rabinowicz, 2004). These new rules caused a need state within all activity system elements of traditional farming. Since old labour intensive tools contradicted with the new rules farmers had to invest in new machinery, varieties, pesticides and other external inputs, which required an increase in production scale and specialisation to keep profitability (Domeij, 1995). This new farming activity was called Conventional Farming (CF). New productivity enhancing tools contradicted with other rural development and environmental functions of the object (Noe et al., 2008; van der Plœg, 2008; Wålstedt et al., 1992) and hence with the old community and its collaborative division of labour designed to support the multifunctional object. As a result productivity per land and labour hour increased while the rural population decreased (Domeij, 1995). This had a negative effect on services and relations in the rural area which further strengthened the rural exodus (Noe et al., 2008; Milestad et al., 2010). Additionally, the new tools caused environmental and health problems (Rydén, 2003; MEA, 2005). Farming became only a matter of producing food while other functions of farming related to food sovereignty, rural life and environment were gradually abandoned in subsequent narrowing developmental cycles. Each narrowing cycle contributed to a farming activity that was fulfilling fewer and fewer of the human needs.

Some farmers experiencing contradictions due to the new rationalisation rules and resulting development of CF converted to the First-wave Organic Farming (FWOF) (Altieri, 1995; Allen & Kovach, 2000; Rigby & Cáceres, 2001; Röling, 2009). This was a divergence from the CF cycle that resulted in an expansive cycle with a new object responding to more human needs than previously. A premium price for added values signalled by a certification label and state subsidies temporarily solved the contradiction between resilient but more labour intensive tools and variable results (Domeij, 1995). The reductionist methods of the old transfer of technology concept that had contributed to the development of CF was in contradiction with the need for multifunctional, integrated and local specific innovations required by the new FWOF activity. The solution to this quaternary contradiction was the innovation of participatory systemic action research and development (Altieri, 1995; Allen & Kovach, 2000; Röling, 2009).

Rationalisation and productivity competition resulted in a continuous product price pressure which could only be temporarily alleviated for early adopters of new innovation. As soon as more farmers adopted the latest innovations the prices fell again. This phenomenon has been called the treadmill (Levins & Cochrane, 1996) and resulted in a majority of the farmers abandoning farming. The treadmill in mainstream agriculture was enhanced when agriculture and land ownership became deregulated from the end of the 1980s (Memorandum 1992/93:LU15; Rabinowicz, 2004) and the relatively low profitability of farming now competed for land with more profitable non-farming related activities, and both national and international land speculators (Latruffe & Le Mouel, 2006; Kjörling, 2011; Östling, 2014).

The sudden and large increase in farmers converting to organic farming as a solution to the contradictions caused by agricultural policies lead to a crisis with an aggravation of contradictions related to the community and division of labour (Rydén, 2003). The new farmers brought with them the hegemonic position of productivity in the object and related large-scale specialised production with distribution in large-scale food chains (Goodman, 2000; Allen & Kovach, 2000; Darnhofer, 2014). As a result organic farmers were pushed back into the price pressing treadmill where premium prices were not enough to maintain profitability (Darnhofer, 2014). Intensive Organic Farming (IOF) was born and with it the familiar contradictions from the productivity enhancing conventional farming activity. Reproduction and development of rural life as well as natural resources and ecosystem services was enhanced in intensive organic farming compared to conventional farming. However, a combination of the price pressure and insufficient support to create the societal context, required by truly organic farming, pushed the productivity hegemony and farmers found themselves in severe dilemmas and double-binds, where short term profitability often was incompatible with long term sustainability and hence long term profitability (Goodman, 2000; Björklund & Johansson, 2010; Darnhofer et al., 2010b; Milestad et al., 2010; Darnhofer, 2014).

Two approaches to solving the contradictions in intensive organic farming can be discerned. One is to stay on top of the treadmill by a continuous increase in scale and productivity through implementation of new technology and concentration of land. The other is attempting to break with the treadmill by finding new ways of expanding the object to become more multifunctional. The means of the latter aim at breaking with the alienation and de-coupling emerging from the large-scale food. New social relations are created which take the form of rural and rural-urban communities with a collaborative division of labour where labour and risks are shared (Björklund et al., 2009; Källander, 2011; Milestad & Kummer, 2012; Darnhofer, 2014). This development is challenged by the scarcely populated rural areas, the domination of large-scale food chains and the lack of societal support for a more localised development.

When comparing the motives and structures of the different activity systems, two conclusions can be drawn. The importance of following ecological principles and hence the strength of the dilemma vary between the farming activity systems. Profitability is achieved by different means depending on how the purpose of farming is perceived. When farming is reduced to a few functions (or aspects of the object) and outcomes such as producing food and maximising profits, profitability is achieved mainly by economies of scale through specialisation, mechanisation, concentration of land productivity and land subsidies and replacing labour with external inputs. The more functions and outcomes farming is perceived to have and produce, the more diverse are the methods of achieving profitability. Different functions, such as food sovereignty, fair income to farmers in combination with affordable prices to consumers, healthy food, reproduction and development of both rural life, urban life, the natural resource base and ecosystem services, are combined in various ways and given different emphasis in each activities object. Profitability in multifunctional farming is achieved mainly by economies of scope, cooperation, strengthening the local resources and ecosystem services, non-agricultural services to the community, rural development subsidies, tourism, direct sale and sharing of risks. Hence two developmental dimensions can be discerned: multifunctionality and ecological sustainability of resource use. The second developmental dimension spans from short-term use of global resources, which are dislocated from their geographical origin and concentrated to the farm, breaking with their natural cycles and causing pollution. At the other end is sustained use of local renewable resources in accordance with their natural cycles.

5.2.2 Actual-empirical contradiction analysis of the PAR groups learning to manage pests in organic apple production

Adding intensive organic apple production (IOAP) to their farms was a solution to the treadmill experienced on the small and medium scale farms of the participatory action research (PAR) group farmers. The IOAP sub-activity system was new to the farmers, as was its related pest management. They joined the PAR group to learn how to control pests efficiently by following organic principles in order to improve the overall profitability of their farms.

Compared to the farms consolidated IOF activity, the apple sub-activity was only recently converting to a more intensive mode of production. Over the three years of the project several challenges of this process were addressed. Most of the groups work focused on the historical tertiary contradiction hypothesis between old versatile and resilient but labour requiring tools and the new hegemonic function of productivity in the IOF object. Two of the challenges are addressed in the present study; a) control of apple sawfly based on a forecasting tool and the botanical pesticide *Quassia amara,* and b) habitat manipulation to enhance natural enemies of apple orchard pests.

The original contradiction of the low efficiency of *Q. amara* was resolved by adapting a forecasting model to Swedish conditions (Paper II) in combination with an improved on-farm method of extracting the botanical pesticide from the wood-chips. New contradictions emerged when the permission to use *Q. amara* was withdrawn awaiting a European safety evaluation and registration process (KemI, 2015). There were indications that the botanical pesticide could be harmful to natural enemies and perhaps humans (McIndoo & Sievers, 1917). The farmers entered into a double bind. On one hand, they faced the risk of loosing one of the few efficient tools against the two potentially devastating pests, namely apple sawfly and aphids. On the other hand, the use of the tool could potentially reduce the resilience of the natural biological control and pose a risk to human health. As a temporary solution the farmers remediated their division of labour by choosing one of the farmers to join an existing pest management advocacy group. The purpose was to influence Swedish authorities to include and prioritise *Quassia* in their attempt to simplify the EU registration process of presumably low-toxic substances. In this way the cost of registration would decrease and the low-toxicity substances could be taken into use as soon as they were determined safe enough.

The idea of habitat manipulation emerged as the farmers were in a dilemma of needing to perform regular pesticide applications to keep damage levels below economic thresholds but knowing that this could harm the natural enemies. Farmers questioned whether or not the efficiency of enhanced natural biological control would be enough, whether the risk of also enhancing pests outweighed the benefits and whether the suggested flower strips would combine with the remaining orchard system and farming practices. The temporary solution became small-scale on-farm field trials and a study visit to Danish farmers using flower strips and other habitat manipulation practices. To manage the variability of result of these developing resilient tools and avoid spraying the Danish farmers had re-thought their object and activity system. Community and division of labour was remediated by localising production and sale with a high degree of direct sale. The direct contact with consumers allowed a larger extent of flexibility in selection of robust apple varieties and gave a higher share of the price to the farmers compared with sale through large-scale food chains. Elaborating products from apples and off farm work increased the income security. The PAR farmers are not interested in this kind of expansion of the object. They wish to strive for a higher yield per hectare and live off the farm without the need of complementing off farm work. Instead, they are remediating the contradictions within the current activity by testing and adapting selected tools to their activity system.

If *Quassia* will be found to be harmful and/or flower strips will not be efficient enough to avoid or strongly reduce pesticide applications it would mean that the original contradictions were not solved by the addition of apple production to the farmers overall farming activity, or by our PAR process. The farmers would be pushed into the double bind again and to a possible questioning and re-thinking of the object and the whole activity instead of just its individual elements.

Since the solutions the PAR group worked on were mainly tool-related, their historical contradiction trajectory were traced in order to see whether an object-historical analysis could provide complementary information on where to search for solutions.

The competitive mechanism of the treadmill shows that there is no end to how cost-efficient the farming activity has to become to avoid farmers losing their land (Levins & Cochrane, 1996). The historical contradictions hypotheses suggest that the specialisation trend in combination with the entry of the large food chains to the community division of labour have been the driving forces behind the hegemony of productivity (Björklund & Johansson, 2010; Darnhofer, 2014). The various forms of direct sale, community-supported agriculture and participatory guarantee systems are examples of where the collaborative rural communities from traditional agriculture are complemented with urban members and organisations to create rural-urban collaborative communities (Milestad & Kummer, 2012; Darnhofer, 2014; Källander, 2011). This breaks with the principles of alienation and competition that drive the treadmill contradictions (Allen & Kovach, 2000). Close social relations where communication of value is facilitated and risks are shared when developing the activity system fitting to the collaborative object replace alienation. Diversity instead of specialisation becomes the driving force for profitability to fulfil the needs of its community element (Björklund et al., 2009). The increased food sovereignty gives potential for developing the activity systems according to the developmental directions. This developmental direction needs to address the challenge of a drained rural population and the technological lock-in of specialisation and large-scale food chains.

Whether the agency (intentional, goal directed actions) in a PAR group is directed towards remediating secondary contradictions within a current activity or expanding the activity by reframing the object, this paper indicates that the root causes and all activity elements should be considered to achieve the multifunctional object. The purpose of CHAT methodology is to offer tools to decide which small-scale experiments to focus on and if the activity needs to move beyond remediating single elements of the current activity system to a re-framing of its object in order to solve its contradictions.

6 Paper II: Evaluation of temperature sum models and timing of *Quassia amara* wood-chip extract to control the apple sawfly in Sweden

Apple sawfly (*Hoplocampa testudinea* Klug) is a serious pest in European organic apple production (Cross et al., 1999). The larvae hatch during a short period only, making correct timing of control measures crucial (McIndoo & Sievers, 1917; Graf et al., 2001; Kienzle et al., 2002). Swedish organic growers have requested a strategy for optimal timing of application of *Quassia amara* (Simaroubaceae) extract against the apple sawfly. One aim of Paper II was therefore to develop methods to predict the timing of *Q. amara* control in Sweden. A temperature sum model for timely placement of monitoring or mass-trapping sticky traps and application of bio-pesticide *Quassia amara* was validated for Swedish conditions.

6.1 Materials and methods

Populations of apple sawfly were monitored during 2011-2013 in seven orchards (1-7) in southern Sweden (table 6.1.1).

Table 6.1.1. *The seven Swedish apple orchards included in Paper II with geographical location, size, production system and experiments conducted.*

Orchard	GPS coordinates (WGS84)	Size (ha)	Production system	Trap observation	Year	Experiment conducted
1	N 55° 43.229', E 14°	0.25	IP	Every day	2011-2013	Trap observation + *Q. amara*
2	N 56° 2.993', E 12°	0.9	Organic	Every day	2011-2013	Trap observation + *Q. Amara*
3	N 56° 27.251', E 12°	10	Organic	Every day	2013	Trap observation + *Q. Amara*

4	N 55° 44.556', E 13°	2	Organic	Twice per week	2011-2013	Trap observation
5	N 55° 36.534', E 14°	1.5	Organic	Twice per week	2011-2013	Trap observation
6	N 55° 39.523', E 14°	12	Organic	Twice per week	2012-2013	Trap observation
7	N 56° 6.886', E 14°	17	IP	Twice per week	2012	Trap observation

Weather data (air temperature, relative humidity and rain) were recorded in each orchard. Rebell Bianco sticky traps were used to record flight pattern and monitor the emergence of adults. At each location, observed adult emergence was compared with the associated predicted emergence based on an existing Dutch temperature-sum construct. The average temperature-sum and standard deviation for all years and orchards was compared against the reference value of 177±10 degree-days (Zijp & Blommers, 1997).

Observed adult emergence was compared locally with apple tree phenology according to the BBCH scale (Meier et al., 1994).

During 2013, egg and larval development was compared with temperature sum forecasts from air temperature, trap catches and apple tree phenology. The egg and larval observations were made every day and due to logistical and time restrictions the study was limited to orchards 2 and 3.

A field trial with wood-chip extract of *Q. amara* was conducted in 2011 and 2012 at orchard 1. The aim was to measure the efficacy of *Q. amara*, applied according to the common commercial practice of spraying at petal-fall (BBCH stage 67-69) (Treatment A), compared with an unsprayed control. In 2013, the experiment was expanded to orchards 2 and 3 and included a study on the efficacy of *Q. amara* timed according to temperature sums (Treatment B). The resulting accumulated curves indicated the theoretical egg hatch peak at which *Q. amara* application was performed. In a third treatment (Treatment C), based on field observations of egg development stages, *Q. amara* was sprayed when the majority of the eggs reached the final development stage F before hatching.

6.2 Results and discussion

After hibernating in the soil, the apple sawfly emerges in spring at a time primarily depending on soil/air temperature (Graf et al., 1996a, 1996b; Zijp & Blommers, 1997). Using the temperature sum construct proposed by Zijp & Blommers (1997), the average emergence of sawflies occurred at 169 degree-days (SD=20) counted from March 15 (threshold temperature 4°C). The difference in emergence from existing first flight model of average and maximum 9 and 39 degree-days (1 and 9 calendar days) was found to be acceptable. First trap catch occurred on average 14 days before full bloom (BBCH 65) and never before April 30. If data on temperature sum are not available, April 30 may be a simpler estimate for trap placement than the commonly recommended 10 days prior to bloom.

Accumulated oviposition of 85% at full bloom (BBCH 65) suggests that mass-trapping and monitoring could stop at this time (Figure 6.2.2). This is supported by a tendency for decreased trap catches during that period. However, only 60% of trapped adult females were caught prior to full bloom (BBCH 65). This indicates that trap catches are not representative of egg deposition after BBCH 64. This inconsistency might explain the problems with finding a significant correlation between total trap catch and fruit damage reported in previous studies (Graf et al., 1996c; Wildbolz & Staub, 1986; Coli et al., 1985). In the orchards studied in Paper II, the first sawfly larva was observed approximately 14 days after the first trap catch, which confirms findings by Miles (1932).

In addition, the observations in paper II indicate that the average time from peak flight to the final larval stage is 32 calendar days (Figure 6.2.1). This information could be used to calculate the timing of entomopathogenic fungi application. Previous studies have shown that entomopathogenic soil fungi (Jaworska, 1992) and nematodes (Vincent & Bélair, 1992) can contribute to decreasing sawfly populations. Therefore in a future integrated approach, commercially available products of entomopathogenic fungi and/or nematodes could be applied just before sawfly larvae enter the soil.

Figure 6.2.1. Fifth larval instar of apple sawfly descending to the soil. Photo: Weronika Świergiel.

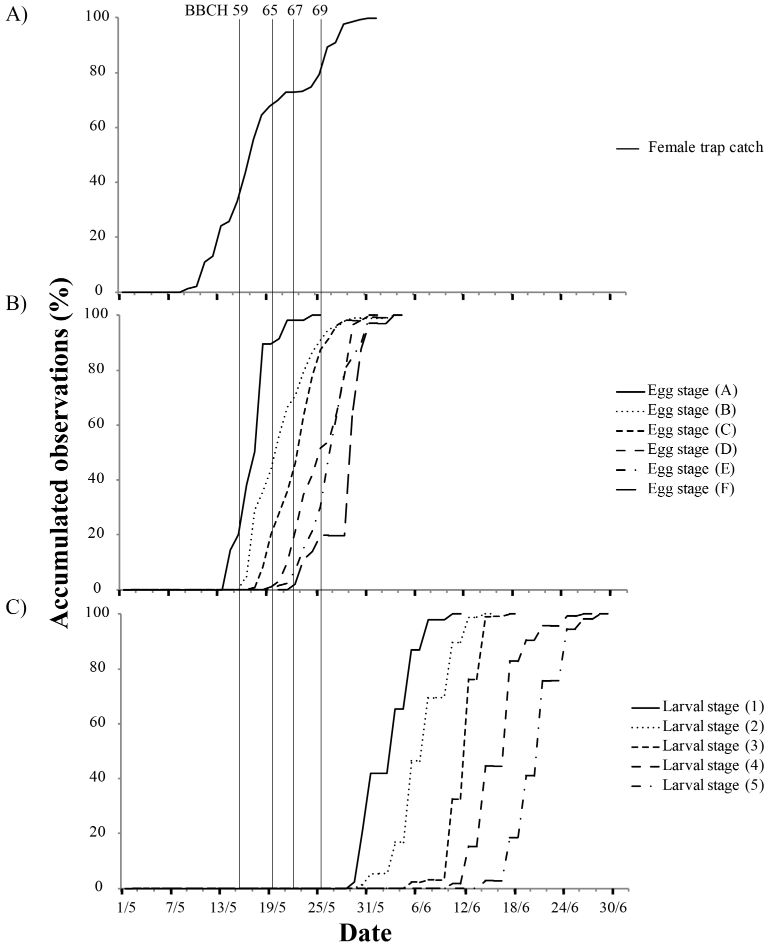

Figure 6.2.2. Apple-tree phenology (BBCH scale as vertical lines), a) accumulated female trap catch counts, b) egg stages and c) larval stages of apple sawfly, as observed across apple orchards 2 and 3 during 2013.

All three application times for *Q. amara* resulted in significantly lower percentage of damaged apples compared with the unsprayed control, with significantly less damage (1.3%) in plots treated according to method (B) (Figure 6.2.3). Growers unable to invest in weather stations for local temperature sum calculations could still use petal fall to time their *Q. amara* application. However, in that case application should not be at 50% petal fall (BBCH 67), but at the end of observed petal fall (BBCH 69).

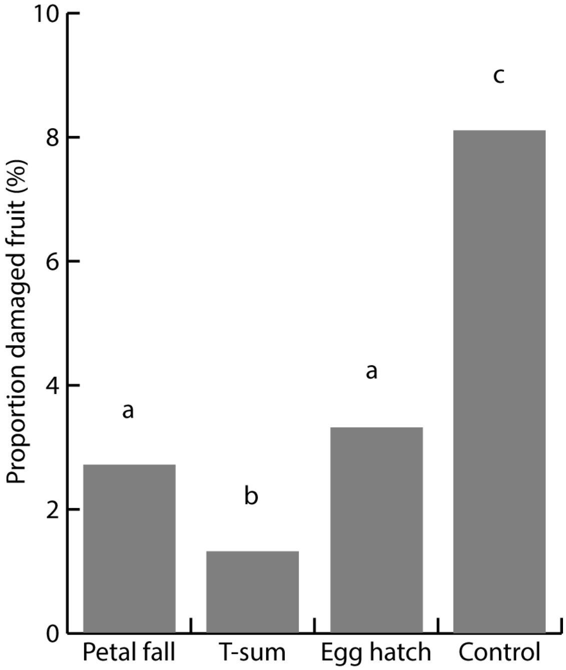

Figure 6.2.3. Proportion of damaged apples after treatment with the botanical pesticide *Quassia amara* at petal fall, according to female trap catches and temperature sum (T-sum), observed egg hatch and unsprayed control. Statistical differences across treatments and control are marked with small letters.

A 4.8-6.8% reduction in harvest results in a loss of 600-1600 Euros/ha in Swedish organic production depending on the productivity of the cultivar. Furthermore, *Q. amara* application prevents a gradual increase in the orchard pest population over the years. *Quassia amara* is available both as an extract and as inexpensive wood chips for separate extraction, whith the latter having been used in Sweden. Swedish growers use *Q. amara* to control both the apple sawfly and the rosy apple aphid simultaneously, which further increases its economic viability. At the moment, a formal registration process for *Q. amara* within the EU is underway.

The results from Paper II confirmed and clarified apple sawfly flight pattern, egg laying and larval activity. The study also showed that results from international studies on apple sawfly phenology can be used in Sweden as an effective tool to determine application timing. However, the findings should be validated with further studies in other regions and years.

7 Paper III: Soil application of *Beauveria bassiana* GHA against the apple sawfly: Field mortality and fungal persistence.

Low impact alternatives to synthetic insecticides for the control of apple sawfly (*Hoplocampa testudinea* Klug) are scarce hindering pest management in organic apple orchards. Paper IV investigated the soil persistence and field efficacy of the entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin strain GHA against apple sawfly under common organic orchard practices. It also assessed the efficacy of *B. bassiana* GHA and *Metarhizium brunneum* Petch (indigenous strain) against sawfly in the laboratory.

7.1 Materials and methods

A laboratory experiment was set up to assess the effect of an isolate of the *B. bassiana* strain GHA biocontrol product (wettable powder) and an indigenous isolate of *Metarhizium brunneum* Petch against field-collected apple sawfly larvae. Larvae were individually inoculated with either 1×10^7 and 5×10^7 conidia/mL. Two controls, one with 0.05% Triton-X 100 and one with sterile water, were included. Each larva was incubated individually and assessed for mortality and fungal growth.

Two separate field experiments were performed in two commercial organic apple orchards. The first experiment (FE1) assessed the long-term persistence of the applied *B. bassiana* product, while the second experiment (FE2) evaluated apple sawfly mortality (FE2a) and fungal persistence during the field season (FE2b). The Dammstorp field site was chosen for the evaluation of sawfly mortality based on its high natural population, indicating favourable conditions for the target pest. Two treatments, application of fungi and control, were randomly distributed within each block. At each site, a temperature logger was placed in the soil at approximately 5 cm depth to measure the temperature once per hour from mid-April to the end of June. A summarising description of laboratory and field experiments can be found in table 7.1.1.

Table 7.1.1. *List of experiments performed, including a short description, site and date (Paper III).*

Experiment	Description	Date	Site
Laboratory experiment (LE)	Effect of *Beauveria bassiana* GHA product and indigenous *Metarhizium brunneum* against the apple sawfly.	June 2013	Laboratory
Field experiment 1 (FE1)	Assessment of entomopathogenic fungi in soil. Indigenous fungi occurrence and surface soil applied *B. bassiana* persistence at 0, 43 and 55 weeks after application.	May 2011-July 2012	Kiviks Musteri commercial orchard
Field experiment 2a (FE2a)	Mortality and mycosis of the apple sawfly after field application of *B. bassiana* GHA with soil incorporation and mechanical weeding.	June-August 2013	Dammstorp commercial orchard
Field experiment 2b (FE2b)	Assessment of entomopathogenic fungi in soil. Indigenous fungi occurrence and soil incorporated *B. bassiana* persistence 1, 8 and 49 days after application.	April-August 2013	Dammstorp commercial orchard

In FE1 and FE2, the commercially available EPF *B. bassiana* strain GHA was applied at the start of peak larval descent to the soil. The application rate was 1.22 g (5.37×10^{10} CFU) per m^2 soil. This amount corresponds to the highest recommended dose for soil application. In FE1 the fungus was applied to the soil surface, while in FE2 it was incorporated into the soil to 12 cm depth by tractor-driven mechanical weeding. To assess apple sawfly mortality in the field, plastic boxes (18 cm wide × 18 cm long × 19 cm deep) were buried in the ground and filled with orchard soil. Ten field-collected larvae were placed on the soil surface of each box. After 49 days apple sawfly cocoons were recovered from the boxes and incubated before dissection under a stereomicroscope. Morphological and molecular identification was performed for the EPF emerging from the dead larvae.

In order to assess the occurrence of indigenous EPF and the short- and long-term persistence of the applied *B. bassiana* product soil samples were collected at different times and plated on selective media for fungal and molecular identification. In FE1, soil samples were collected before and just after application and at 43 weeks and 55 weeks after application. In FE2, sampling was performed before and just after application and at 8 days and 49 days after application. In addition, entomopathogenic fungi were isolated from FE1 soil samples using insect bait for qualitative assessment of EPF occurrence. Larvae were checked for mycosis weekly for four weeks and emerging EPF were isolated on SDA and morphologically and molecularly identified.

7.2 Results and discussion

Larvae treated with either fungus in the laboratory died faster than control larvae and displayed 49.4-68.4% mycosis (Table 7.2.1).

Table 7.2.1. *Hazard ratios (± SE) and observed relative mycosis of sawfly larvae for each fungal treatment in infection bioassays. The low and high concentrations used corresponded to 1×10^7 and 5×10^7 conidia/mL, respectively. Test statistics (z) and significance differences relative to control treatments are from multiple pairwise comparisons by Tukey contrasts (Paper III).*

Treatment (n)	Hazard ratio (SE)	z-value	P-value, Tukey contrasts	Relative mycosis
KVL14-87 *B. bassiana* GHA low (79)	1.3207 (0.1404)	1.981	0.2737	49.4%
KVL14-87 *B. bassiana* GHA high (69)	1.6080 (0.1408)	3.372	0.0067	62.3%
KVL14-90 *M. brunneum* low (79)	1.6886 (0.1424)	3.680	0.0021	68.4%
KVL14-90 *M. brunneum* high (78)	2.2273 (0.1441)	5.559	<0.0001	65.4%

In the field, *B. bassiana* density remained high in the week after application, during larval descent to the soil. Fungal density decreased to 25% at 49 days after application (Figure 7.2.1) and to 0.4% after 55 weeks (Figure 7.2.2).

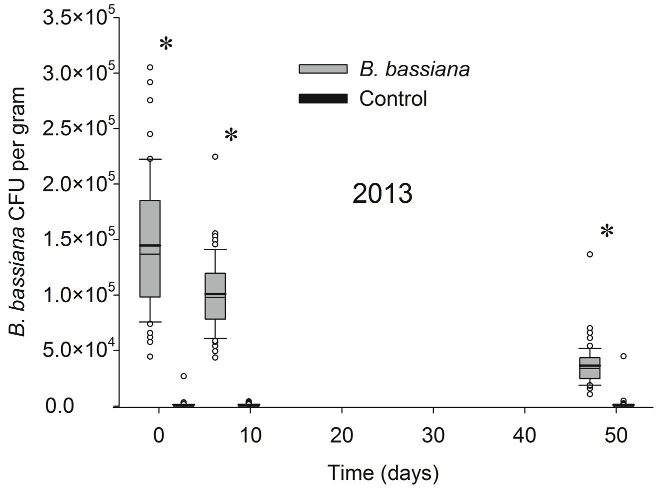

Figure 7.2.1. Boxplot of *Beauveria bassiana* persistence in field experiment 2b (FE2b, 2013) at 1, 8 and 49 days after *B. bassiana* application. Bold lines represent average values and standard lines median values of number of Colony Forming Units (CFUs) per g dry soil. * indicates statistically significant difference (GLMM; Wald test, $p < 0.01$).

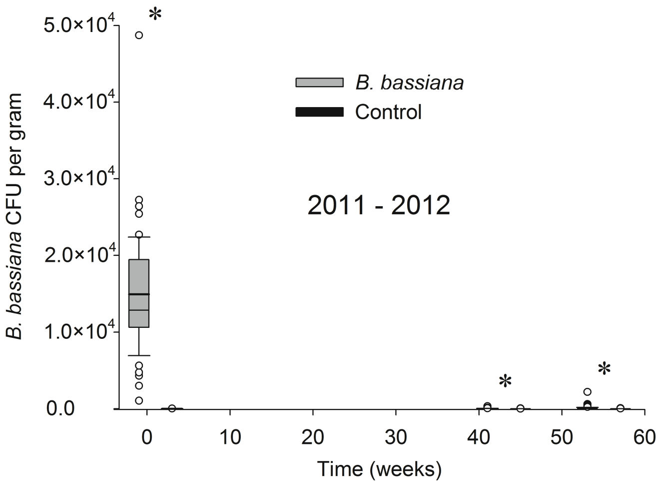

Figure 7.2.2. Boxplot of *Beauveria bassiana* persistence in field experiment 1 (FE1, 2011-2012) at application (0) and 43 and 55 weeks after application of *B. bassiana* strain GHA. Bold lines represent average values and standard lines median values of number of Colony Forming Units (CFUs) per g dry soil. * indicates statistically significant difference (GLMM; Wald test, $p < 0.01$).

Molecular markers revealed that the majority of fungal isolates recovered comprised the applied *B. bassiana* strain GHA. Larvae pupating in soil cages in the orchard for 49 days displayed 17% mycosis. However, the high efficacy measured under laboratory conditions was not confirmed in the field. *Beauveria bassiana* application resulted in densities above the upper natural background level during the growing season, although reversion to background levels occurred within a year.

There is an urgent need to find environmentally friendly control methods for the apple sawfly, as its population size increases rapidly if left untreated (Zijp & Blommers, 2002). Application of EPF to the soil could help reduce the sawfly population in the following year and facilitate efficient control with *Q. amara* at egg hatch. However, field application of *B. bassiana* under common organic orchard practices did not provide a sufficient control effect against apple sawfly when evaluated in a single season. Additional work is needed to bridge the knowledge gap between laboratory and field efficacy in orchards. It remains to be investigated whether the elevated fungal densities caused by either annual or occasional applications have a detrimental effect on non-target organisms.

8 Conclusions and future perspectives

During this Participatory Action Research (PAR) project on pest management in Swedish organic apple production, several pests and control methods were addressed, with the main focus on the apple sawfly (*Hoplocampa testudinea* Klug). An interdisciplinary methodology and PAR approach was employed, including participatory meetings, interviews and field and laboratory experiments. As the project progressed, a need emerged to find a theory and tools that could support participatory problem formulation by identifying the historical root causes of the pest problems being experienced and explain the main drivers behind their development. CHAT offers analytical tools for re-framing an issue that can be employed in a PAR group to increase its potential to formulate and act in the participatory and systemic way needed to generate sustainable solutions (Engeström, 1987). CHAT analysis is based on both contradiction manifestations, as they are experienced by the participants, and a collaborative object formulation (*ibid*). This agrees with the PAR approach of experience-based understanding and learning (Kolb, 1984).

By the end of the project, the PAR group had developed an efficient pest management tool based on forecasting and the botanical pesticide *Quassia amara* L (Paper II). Soil application by *Beauveria bassiana* (Balsamo) Vuillemin was found to be an insufficient control method and requires further investigations to bridge the gap between laboratory and field results (Paper III). The basic problem, or contradiction, related to having to perform regular pesticide applications with the risk of damaging natural enemies was temporarily solved for some pests, while others required more sprays and higher doses.

The CHAT methodology may facilitate PAR by offering a theory explaining how and why learning occurs not in an abstract and isolated manner in our minds, but when we interact with things and people trying to solve problems in practice; that we create an understanding, or give a meaning, to things not on our own, but by interacting with other people in a particular historical and cultural context. CHAT also offers a theory of how the drivers of development are rooted in the specific societal structure or mode of production in each cultural historical context. In our current context, the driver is a contradiction between the use value and exchange value that affects all parts of our activities in one way or another. It also reveals the often taken-for-granted political-cultural context, opening up the possibility of finding or creating new contexts. Based on CHAT, a methodology and tools have been developed to include the psychological, pedagogical and developmental theories into applied research and development aimed at improving practice.

The historical analysis in Paper I revealed that due to the competitive mechanism of the treadmill, there is no end to how cost efficient the farming activity has to become to avoid farmers losing their land (Levins & Cochrane, 1996). The treadmill means that when production and consumption are driven by competition, new technologies may temporarily generate greater profitability for the early adopters of the technology. However, as soon as more people start adopting the technology there is no longer any competitive advantage and prices are once again pressed down. The historical analysis in Paper I shows how this has contributed to a large rural exodus and a conflict between (1) the methods of production aiming at a continuous decrease of production costs and increased productivity in order to keep prices low on the one hand, and (2) ecological and social sustainability on the other. Intensive organic farming has alleviated, but still not solved, this basic conflict. Hence some environmental problems, such as broken nutrient cycles, pollution, climate change and a low resilience in natural biological control, still present a challenge, as do the social problems that are manifested, such as rural exodus, loss of food sovereignty, organic food being too expensive for some parts of society and the economic problems of a continued treadmill (e.g. Levins & Cochrane, 1996; Local Harvest; Rigby & Cáceres, 2001; Björklund & Johansson, 2010; Darnhofer et al., 2010a).

The historical analysis suggests that the trend towards specialisation in combination with the entry of the large food chains (many intermediaries on both the input and output side of farming) have been the driving forces behind the hegemony of productivity increase at the expense of ecological and social sustainability and rural development (Allen & Kovach, 2000; Goodman, 2000; Rigby & Cáceres, 2001; Milestad et al., 2010; Darnhofer, 2014). These issues are being addressed both by the Danish farmers mentioned in this study and in various examples found through the historical analysis. The community and division of labour are altered to replace large food chains that function by profit-maximising principles (Altieri, 1995; Björklund et al., 2009; Wezel et al., 2009; Milestad & Källander, 2011; Kummer, 2012; Darnhofer, 2014). To have the freedom to define farming so that it fits with its multifunctional object (combining profitability with true ecological and social sustainability and rural development), many farmers are replacing specialisation, intensification of unsustainable resource use and large food chains with collaboration, diversification and an increased localisation of production and consumption (*ibid*).

The common disciplinary framings in research and development activities create preconceived expectations about which part and function of a farming system should be addressed. In the PAR group the main expectations were to work on the productivity function by developing organic crop protection tools. However, the kind of pest management tools that will be perceived as desirable and feasible will always depend on the wider farm, food and social context. Jerneck & Olsson (2011) describe problem formulation as framing based on subjective understanding or specific theoretical lenses of scientific disciplines. Hence, each researcher and farmer who joins a PAR group views the issues through their own frame and may think that all aspects are included or that some aspects mentioned by other participants are not part of the issue. At the same time, the stakeholders' motivation and actions to change will come from their own understanding of the problems (McCown et al., 2009). Therefore, a participatory formulation of problems and solutions assisted by theories and tools revealing the historical and systemic nature of the problems being experienced are required.

If the root causes and interpretations of contexts are to become a part of farmers' decision-making, they ought to be generated, at least partially, by a collaborative approach based on the historical experiences of the participants together with the wider historical development. PAR allows the creation of a platform where multivoicedness is present in the activity. This could help direct the historical analyses so that they include all the functions and motives of farming. The polyocularity approach suggested by Noe et al. (2008) assumes that an object is always multifunctional and that stakeholders must be made aware of this and learn to take it into account when working together. Perhaps there are synergies to be achieved between the theories underpinning polyocularity and CHAT.

For future perspectives I suggest that the theory and associated methodology and tools of CHAT may be useful in PAR projects based on the pragmatic or transformative paradigms that are pluralistic in their methods of inquiry (Mertens, 2015).

The cycle of expansive learning in CHAT shows some similarity with PAR iterative cycles (e.g. Kolb, 1984) and the soft systems methodology developed by Checkland (e.g. Checkland & Holwell, 1998; Checkland, 2000). I suggest that CHAT may contribute to these cycles and to systemic thinking in at least five ways: 1) with its definition of the smallest unit of analysis, which still includes the essence of the whole that could help to avoid the pitfalls of reductionism; 2) with a method of historical analysis; 3) with an explicit theory of change based on the contradictions related to elements of an activity system; 4) with the formation of an object towards which purposeful action is directed; and finally 5) with the incorporation of the social aspect and mediation in knowledge construction. Historical dynamism, structure, innovation, social knowledge construction and mediation are therefore built into the system concept. These points also relate to the way generalisation is seen in CHAT. To study phenomena changing over time, their structure and logic of development need to be integrated into how a generalisation is achieved (Pihlaja, 2005). The CHAT concept of generalisation may be a way to facilitate a structured transfer and adaptation of knowledge created in one PAR case to other cases, which is an aspiration of PAR. However, a wider range of issues and contexts in PAR enquiries need to explore the use of CHAT in order to answer the question to which extent all the different issues of PAR studies are efficiently understood as activity systems and networks of activities, and developed using the theory of expansive learning and developmental work research methodology.

Although we have not employed empirical testing of social phenomena, I would still argue that they could be of value on the assumption that at least some phenomena for some time are more or less persistent in their essence. However, I agree with Kurt Lewin (Chaiklin, 2011) and Engeström (1987) that they could not in isolation explain any general phenomena or their local manifestation, nor that they translate into every historical and cultural context. If we understand the societal object of an activity to be a social phenomenon, a CHAT perspective would also stress that a general societal phenomenon does not explain the individual personal sense of that phenomenon (Engeström, 2001). Wells (2011) provides an illustrative account of how in the course of his career he discovered the need and usefulness of combining both empirical and theoretical generalisations using a PAR approach and CHAT in developing teaching and learning. In conclusion, a generalisation of activities in the CHAT sense could be useful to a PAR project with the aim of supporting societal practice, and it will need to be complemented with local specific and personal sense inquiries. In actual fact, one supports the other.

Finally, it is important to mention that acquiring the analytical tools for the reframing of a problem and possible solutions is not enough. There must be institutional support for this kind of research activity (Engeström, 1987). According to Jerneck and Olsson (2011), the strong paradigms in natural sciences may see reframing as alien or even unscientific. Furthermore, there must also be motivation and action towards reframing the problems (Vänninen, Pereira Querol, Engeström 2015) among farmers, researchers, funding bodies and policy makers alike.

Universities, funding bodies and PAR stakeholders need to become accustomed to new kinds of research and development in which the first step is to develop an understanding of the system. If expansive learning in multidisciplinary teams together with the relevant stakeholders were to be the object of research and development, crop protection researchers and their tools would be one activity system in a collaboration of activity systems with the partially shared object of resolving contradictions in farming. Farmers would have a forum in which their entire multifunctional object is taken into consideration by a mix of competences including the analytical tools of CHAT, instead of being dealt with by alienated learning activities. Separate learning activities lead to reductionist solutions that enforce rather than resolve contradictions. The task of crop protection researchers would then not be to intend to solve the treadmill-related contradictions by developing productivity-enhancing tools. Instead, it could be to develop resilient tools in collaboration with subjects of other competences. These would redesign or reframe farming collaboratively to solve the root causes of problems or rather the primary contradictions of farming to achieve a sustainable activity system. The solutions would be implemented since they would be designed with farmers to solve the contradictions they experienced.

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