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Welfare Risk Accumulates Across the Animal Life Course: A Longitudinal Veterinary Framework Linking Early Experience, Housing, Health, Pain, Handling, Transport, Production Demands, Adaptation, Recovery, and End-of-Life Decisions

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ABSTRACT

Animal-welfare assessment commonly describes an animal at a particular observation point, although the observed state may reflect exposures, adaptations, and incomplete recoveries accumulated over months or years. This article develops an original non-empirical longitudinal framework for interpreting welfare across the animal life course. It integrates prenatal and early-life conditions, maternal and social environments, housing, disease, pain, human contact, transport, production transitions, reproductive and metabolic demands, adaptation, recovery, and end-of-life decisions. The central argument is that neither the number of adverse events nor the animal's current appearance adequately represents cumulative welfare. Interpretation must also consider exposure intensity and duration, recurrence, temporal clustering, prior vulnerability, positive experience, adaptive response, opportunity for recovery, and the possibility that apparently stable function conceals physiological or behavioural cost. The proposed architecture therefore separates exposure history, current multidomain state, adaptive capacity, recovery trajectory, and future vulnerability. It also distinguishes reversible compromise from persistent or uncertain change and identifies critical transitions at which concurrent demands may exceed available reserve. The framework is intended to organize assessment and research rather than provide a numerical score, diagnostic threshold, or validated prediction rule. Its transferability is constrained by substantial differences among species, production systems, companion-animal contexts, individual animals, measurement methods, and caregiver resources. Prospective longitudinal studies are needed to determine whether the proposed distinctions improve welfare interpretation or decisions beyond repeated cross-sectional assessment.

Keywords: Animal welfare, Life-course assessment, Cumulative burden, Adaptation, Recovery, Critical transitions

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Introduction

Veterinary welfare decisions are often made from observations obtained during a farm visit, clinical consultation, handling event, transport inspection, or end-of-life assessment. Such observations are necessary but temporally incomplete. A productive animal may retain output while developing metabolic or inflammatory burdens, and a clinically quiet animal may carry consequences of earlier pain, deprivation, disease, or repeated disruption.

Conversely, an adverse event need not produce persistent compromise when its intensity is limited and effective recovery follows. Farm-animal evidence supports concern that welfare consequences can develop progressively across productive life, while the Five Domains Model establishes that physical conditions, behavioural interactions, and mental experience must be interpreted together [1, 2].

Welfare also cannot be represented solely as accumulated harm. Positive welfare includes rewarding experience, competence, and resilience, while repeated human contact can become positive, neutral, or aversive according to learning history, predictability, agency, and individual response [3, 4]. This article therefore proposes a longitudinal veterinary architecture that treats welfare as a time-dependent configuration rather than a succession of isolated scores. It separates exposure history from current state, adaptation from welfare neutrality, functional recovery from complete recovery, and chronological age from end-of-life justification. The framework integrates farm, clinical, companion-animal, and other managed-animal evidence cautiously; it does not assume that mechanisms, indicators, or acceptable decisions transfer unchanged among species and settings.

Why welfare requires a life-course perspective

A cross-sectional assessment asks what is observable now. A life-course assessment additionally asks how the animal arrived at that state, whether similar disturbances have occurred before, what recovery was possible, and how the present condition changes vulnerability to the next challenge. Identical findings can therefore have different meanings. Reduced activity may represent acute pain, learned avoidance, energy conservation, age-related change, or a residual response after repeated disturbance. Normal production may accompany effective adaptation, delayed deterioration, or an insensitive outcome measure.

The life-course perspective proposed here does not require every experience to be converted into a common unit. Instead, it preserves six temporal properties: onset, intensity, duration, recurrence, clustering, and recovery. It also distinguishes adverse exposure from experienced welfare, because the same environment may be perceived differently according to phenotype, developmental history, health, social context, and controllability. Positive experiences should likewise be located temporally: they may improve the current state or build competence, but they cannot be presumed to cancel pain or disease. Longitudinal interpretation is therefore configurational rather than additive. Its purpose is to identify trajectories and conditional vulnerability without fabricating a cumulative score.

Prenatal and perinatal conditions

The animal life course begins before birth. Maternal pain, disease, nutritional disturbance, heat exposure, social instability, and handling may alter the intrauterine environment while also compromising maternal welfare. In pigs, lameness during pregnancy has been associated with altered offspring weight gain, skin lesions, vocalisation, and behavioural responses, although glucocorticoid findings were not uniformly different [5]. The evidence supports prenatal carry-over under defined conditions, not a conclusion that maternal adversity inevitably produces permanent offspring impairment.

Prenatal risk is also unlikely to operate through one independent exposure. Group-housed sows may encounter restricted feeding, competition, poor flooring, heat, limited rooting opportunities, mixing, lameness, and variable stockmanship. These conditions can interact through maternal stress, pain, resource access, and health, yet their relative contributions remain incompletely separated [6]. The proposed framework therefore treats the prenatal and perinatal period as an initial susceptibility-setting interval. Maternal condition, placental mediation, birth difficulty, neonatal vitality, colostrum access, and immediate care should be recorded as linked but distinct components. Later welfare findings must not be retrospectively attributed to prenatal exposure when genetics, postnatal management, infection, or subsequent social experience provide plausible alternatives.

Neonatal and early-life experience

Early life combines rapid physiological development with dependence on caregivers, maternal contact, nutrition, thermal support, housing, and social learning. Experiences during this period may affect immediate comfort and health while also influencing how the animal responds to novelty, regrouping, handling, weaning, or resource competition. The relevant question is therefore not simply whether an early exposure was adverse, but whether it altered behavioural opportunity, competence, fear, social flexibility, or susceptibility during later transitions.

Developmental effects should nevertheless be interpreted cautiously. Early individual housing, maternal separation, disease, painful procedures, or inconsistent human contact may occur together, making attribution

difficult. Later behaviour can also reflect current conditions rather than a fixed early-life imprint. The proposed architecture consequently records early experience as a modifying history, not a deterministic label. Evidence of play, exploration, feeding independence, social interaction, growth, clinical health, and response to novelty should be considered jointly and repeatedly. An apparently successful transition does not prove absence of earlier compromise, whereas a later welfare problem does not by itself establish developmental causation. Longitudinal studies must distinguish persistence, delayed expression, compensation, and recovery.

Maternal and social environment

Social opportunity is not adequately described by the binary categories "individual" and "group" housing. A systematic synthesis of dairy-calf evidence found that outcomes varied with age at social introduction, group size, stocking density, group stability, age composition, available space, and enrichment; early placement in pairs or small groups showed behavioural or performance advantages without consistent evidence of health harm, whereas some larger-group arrangements complicated feeder adaptation [7]. Social exposure must therefore be interpreted through its configuration.

Commercial comparisons provide an additional systems perspective. Austrian farms using cow–calf contact differed from early-separation farms in qualitative behaviour, space, pasture access, disbudding practices, and several clinical findings, but those differences cannot all be attributed to maternal contact because farms selected and managed their systems as packages [8]. Earlier synthesis similarly indicates that prolonged contact may support more normal social behaviour while intensifying later separation responses and reducing saleable milk during nursing [9]. Maternal contact, peer contact, crowding, instability, competition, and separation are thus analytically distinct. The proposed framework records both the benefits available during contact and the welfare consequences of how contact is changed or terminated.

Housing conditions

Housing is a continuing exposure platform rather than a static description of floors, pens, cages, shelters, or pasture. It regulates thermal comfort, rest, movement, social choice, feeding access, injury risk, pathogen exposure, human contact, and opportunities for rewarding behaviour. A physically clean environment may still constrain agency or social development; conversely, group housing may provide social opportunity while introducing competition, instability, or unequal resource access. Interpretation must therefore connect resources to animal-based evidence.

The proposed concept of housing-state discordance describes disagreement between nominally acceptable resources and behavioural, clinical, or physiological findings. Housing-state convergence describes alignment between suitable resources and evidence that animals can use them without sustained competition or compromise. Neither category is a validated score. Individual vulnerability, group composition, climate, disease, life stage, and previous housing may modify both states.

Because these configurations are difficult to compare accurately in linear prose, the following matrix separates the housing condition from its observable consequences, interpretive boundary, and reassessment need. **Table 1** presents housing configurations tested against agency, social stability, maternal contact, and animal-based outcomes.

Table 1. Housing configurations tested against agency, social stability, maternal contact, and animal-based outcomes

Housing configuration	Resource promise or interpretive problem	Animal-based support or contradiction	Conditions changing meaning	Management test
Resource-adequate, behaviourally restrictive	Physical provision may conceal unmet behavioural opportunity	Low exploration, rebound behaviour, abnormal repetition	Species, age, prior housing	**Response:** Examine agency and usable space **Test:** Reassess after environmental change
Socially enriched, stable	Contact may support competence and positive experience	Play, affiliative contact, distributed resource use	Group size, familiarity, escape space	**Response:** Preserve effective social configuration **Test:** Verify health and subordinate access
Socially unstable or crowded	"Group housed" may conceal competition and repeated disruption	Aggression, lesions, displacement, uneven intake	Mixing, density, feeding design	**Response:** Reduce instability or resource conflict

Housing configuration	Resource promise or interpretive problem	Animal-based support or contradiction	Conditions changing meaning	Management test
				Test: Repeat after regrouping
Maternal-contact system	Benefits coexist with later separation demands	Maternal behaviour, calf activity, separation response	Contact duration, nursing, separation method	**Response:** Plan contact and withdrawal together **Test:** Follow beyond separation
Housing-state discordance†	Resources and animal outcomes disagree	Acceptable inputs with adverse animal-based findings	Disease, climate, individual susceptibility	**Response:** Investigate latent or unmeasured hazards **Test:** Treat classification as provisional

†Proposed interpretive category; it is not an additive welfare score.

Health and disease burden

Disease affects welfare through more than diagnosis or treatment cost. Pain, malaise, impaired movement, altered appetite, social displacement, treatment burden, recurrence, and time spent without effective relief may differ markedly among disorders. Reviews of dairy production disease show that economic, welfare, environmental, and public-health burdens are measured with non-equivalent approaches and that welfare consequences require attention to severity, duration, incidence, and recurrence [10]. A brief severe episode and persistent lower-grade disease should not automatically be ranked by peak severity alone.

Emerging composite methods illustrate both opportunity and risk. A machine-learning-derived cumulative health measure combined behavioural and pathophysiological features across dairy diseases, but temporal inconsistency, dataset variability, and the need for larger external validation limit interpretation [11]. Modeling work likewise suggests that frequent or prolonged production-disease episodes can contribute substantial herd-level burden even when individual cases appear less severe [12]. These approaches support duration-sensitive assessment but do not establish a universal welfare currency. The proposed framework therefore records disease onset, persistence, recurrence, treatment response, residual impairment, and intercurrent disease separately. Composite interpretation should remain transparent enough to reveal which component drives concern.

Painful procedures

A painful procedure is often documented as a discrete management or clinical event, yet its welfare significance extends before and after the procedure itself. Anticipatory handling, restraint, tissue injury, analgesic adequacy, inflammatory duration, wound complications, repeated performance, and interference with feeding, mobility, maternal contact, or social behaviour form a procedure–recovery episode. Multiple procedures placed close to weaning, transport, regrouping, or disease may create a different welfare trajectory from the same procedures separated by effective recovery.

The proposed framework therefore distinguishes procedural exposure from pain experience and pain experience from recovery. Observable behaviour, function, wound state, sensitivity, intake, social engagement, and response to handling should be interpreted over relevant timescales rather than at one convenient observation. Absence of conspicuous behaviour cannot establish absence of pain, particularly when species-specific concealment, restraint, exhaustion, or competition suppresses expression. Conversely, transient behavioural change does not demonstrate persistent impairment. Procedure-specific analgesic efficacy and recovery periods cannot be inferred from the present cross-domain evidence base. They require species-, procedure-, age-, and treatment-specific evidence, while longitudinal assessment should document whether recovery was complete before another major demand occurred.

Handling and human contact

Human contact ranges from routine feeding and inspection to restraint, treatment, loading, and slaughter handling. Repeated interactions can shape approach, avoidance, predictability, and fear, while stockperson attitudes and behaviour influence whether contact is experienced as threatening or rewarding [13]. This relationship is reciprocal: animals that are ill, fearful, inexperienced, or difficult to move may alter handler behaviour, and organizational time pressure or poor facilities may constrain even knowledgeable handlers.

Acute handling quality and longitudinal human–animal relationship should therefore be measured separately. Event-based assessments can detect falls, slips, balking, vocalisation, electric-prod use, forceful restraint, and overt abuse during bounded handling episodes [14]. Farm-level work in pig production further indicates associations among stockperson attitudes, husbandry practices, animal welfare, and productivity, but observational relationships do not establish a single causal direction [15]. The proposed architecture treats handling as both an immediate exposure and a learned history. Improvement may require training, predictable routines, appropriate restraint, facility redesign, adequate staffing, and attention to pain or disease. Positive contact cannot compensate for structurally poor housing or untreated illness, and low event counts during one inspection cannot establish a consistently positive relationship.

Transport and relocation

Transport combines handling, confinement, unfamiliar sensory conditions, altered social composition, motion, thermal exposure, and restricted access to rest, water, or feed. Its welfare meaning depends partly on the animal's condition before loading and the opportunity to recover afterward. A clinically compromised, heavily pregnant, recently weaned, socially inexperienced, or previously transported animal may enter the same journey with different vulnerability. Observable handling outcomes can identify acute failures, but they cannot reconstruct the complete journey or prior exposure history [14].

Relocation without a vehicle can produce similar disruption when animals encounter novel housing, regrouping, changed caretakers, or unfamiliar feeding systems. The proposed term transition-state carry-over denotes effects that remain when the transport or relocation event has ended but behavioural, physiological, social, or functional recovery has not. This status cannot be inferred from arrival alone.

Table 2 presents welfare questions answered before departure, at arrival, and during post-movement recovery.

Table 2. Welfare questions answered before departure, at arrival, and during post-movement recovery

Movement configuration	Pre-movement vulnerability	Transition or arrival evidence	Meaning at unloading	Action before closure
Prepared, stable movement	Fitness, familiarity, compatible group	Controlled loading, preserved posture, prompt settling	Limited observable disruption	**Action:** Maintain safeguards **Unresolved:** Hidden physiological change possible **Later check:** Confirm feeding, rest, and social integration
High-density transition cluster†	Weaning, mixing, pain, heat, pregnancy	Balking, aggression, exhaustion, disrupted intake	Concurrent demands may amplify vulnerability	**Action:** Reduce avoidable co-occurrence **Unresolved:** Effects cannot be assigned to one hazard **Later check:** Reassess across multiple domains
Adverse arrival state	Pre-existing disease, journey duration, poor facilities	Injury, dehydration, immobility, persistent agitation	Welfare compromise requires action	**Action:** Treat, rest, modify onward movement **Unresolved:** Departure and journey contributions may be unclear **Later check:** Document response and residual impairment
Apparent arrival stability†	Adaptation, suppression, insensitive indicators	Normal movement with delayed behavioural or clinical change	Recovery remains unconfirmed	**Action:** Avoid closure at unloading **Unresolved:** Stability may conceal cost **Later check:** Repeat assessment after an appropriate interval

†Proposed longitudinal classification, not a transport-risk score.

Production transitions

Production transitions reorganize several domains simultaneously. Weaning changes nutrition, maternal or peer contact, microbial exposure, housing, and human management. Experimental evidence in pigs shows that weaning age can alter physiological, behavioural, and performance indicators, but the findings do not establish one age as optimal across production systems [16]. Welfare assessment should therefore examine the configuration of the transition, not age alone.

Transport represents another compound transition. Its hazards include loading and unloading, thermal conditions, confinement, resource deprivation, motion, social disruption, and pressures for logistical efficiency [17]. Periparturient dairy cows face a different configuration: rapidly increasing metabolic demand, reduced intake, inflammation, parturition, lactation, and elevated disease susceptibility require coordinated monitoring rather than reliance on milk production alone [18].

The proposed concept of transition density refers to the number and interaction of major demands compressed into a limited recovery interval. It does not assume mathematical additivity. Its practical purpose is to identify avoidable clustering—for example, combining painful procedures, abrupt dietary change, regrouping, and transport—while recognizing that evidence for the independent contribution of each element may remain uncertain.

Reproductive and metabolic demands

Reproduction can alter welfare through pregnancy, parturition, lactation, maternal behaviour, nutrient allocation, and repeated breeding cycles. These demands are biologically expected but not welfare-neutral when housing, nutrition, health care, or recovery opportunities are insufficient. Selection for high output may further create mismatch between productive demand and structural or physiological capacity [1]. The relevant distinction is not between "natural" and "unnatural" demand, but between demand that remains supportable and demand associated with sustained negative experience or organ-system compromise.

Metabolic indicators should be interpreted with behaviour, body condition, disease, intake, mobility, and reproductive stage. A temporary change may reflect successful physiological adjustment, whereas persistent negative energy balance, repeated disease, or delayed functional recovery may indicate narrowing reserve. Conversely, high production cannot prove good welfare, and lower production cannot diagnose compromise.

The proposed architecture treats reproductive and metabolic demand as a time-varying load whose significance depends on parity, phenotype, prior disease, environmental conditions, concurrent social stress, and the interval available for restoration before the next reproductive or production challenge.

Cumulative welfare load

Dynamic welfare assessment requires repeated attention to appetitive and adverse factors relative to the animal's capacity to adapt [19]. The proposed construct cumulative welfare load is therefore not a count of diagnoses or unpleasant events. It denotes the temporally configured influence of exposure intensity, duration, recurrence, clustering, prior susceptibility, positive opportunity, and incomplete recovery on the animal's present and future welfare.

Lifetime-use recommendations for research animals similarly emphasize that severity, repetition, duration, and recovery should be considered together, although their governance context and thresholds cannot be transferred directly to farms or companion animals [20]. Dairy health research also demonstrates that time-based summaries can capture information that cumulative disease frequency omits [21]. Health records, however, remain incomplete proxies for affective welfare.

Accumulation may occur through persistent exposure, repeated reactivation, reduced reserve, or interruption of recovery. Protective experience may improve competence or controllability without erasing earlier pain. The framework consequently rejects simple subtraction of positive from negative events. It instead asks which effects remain active, which have resolved, and which alter the response to the next challenge.

Adaptation versus hidden cost

Adaptation is often inferred when behaviour, production, or routine clinical measures stabilize. That inference is unsafe if the monitored outcome is insensitive to continuing effort or if the animal has changed behaviour to avoid an uncontrollable challenge. Stable milk yield, reduced vocalisation, immobility during handling, or lower interaction may represent successful coping, learned predictability, exhaustion, suppression, or disease. No single interpretation follows from stability alone.

The proposed term hidden cost refers to welfare-relevant physiological, behavioural, or opportunity loss that is not captured by the principal monitored outcome. It is a hypothesis requiring corroboration, not a diagnosis. Evidence might include cross-domain discordance, prolonged recovery, altered social engagement, recurrent disease, reduced behavioural repertoire, or continuing resource dependence despite apparently restored output.

Adaptation should therefore be evaluated against an explicit baseline and across time. When the pre-exposure baseline is unavailable, comparison with the animal's own later trajectory, suitable peers, and convergent indicators may reduce—but cannot eliminate—uncertainty. Apparent coping should neither be dismissed as false nor accepted automatically as welfare neutrality.

Recovery and reversibility

Recovery is multidimensional. Following relocation to an enriched enclosure, dairy cows showed behavioural and physiological changes occurring on different timescales, illustrating that early stabilization of one indicator need not mark completion of adaptation [22]. Environmental enrichment may build competence and functional resilience, but benefits vary with enrichment design, developmental history, motivation, and opportunity for use [23]. Data-driven milk trajectories can quantify perturbation magnitude, duration, and return, yet production recovery remains an incomplete welfare proxy [24].

The proposed framework distinguishes observed recovery, partial recovery, unresolved recovery, and uncertain recovery. Reversibility is a stronger inference: it requires evidence that relevant effects can return toward an appropriate baseline without unacceptable continuing support or relapse.

Because these states impose different evidential burdens, the following register separates what can be concluded from what remains unverified. **Table 3** presents what functional return, multidomain recovery, and reversibility each require.

Table 3. What functional return, multidomain recovery, and reversibility each require

Recovery question	Observed multidomain recovery	Functional return only	Partial or unstable recovery	Uncertain recovery
Strength of reversibility inference	Plausible, not guaranteed	Undetermined	Limited or conditional	Not inferable
Baseline or residual-exposure conditions	Baseline quality, low residual exposure	Production pressure, compensatory effort	Recurrent disease, inadequate environment	Missing baseline, sparse measures
Domains observed	Convergent behavioural, clinical, physiological return	Output restored; other domains unresolved	Improvement with residual signs or relapse	Inconsistent or insufficient observations
Management disposition	Resume routine surveillance	Continue targeted monitoring	Modify treatment or environment	Avoid declaring resolution
What remains unverified	Future relapse remains possible	Function is not total welfare	Baseline may have shifted	Absence of evidence is non-confirmatory
Observation needed next	Check at next transition	Add behavioural and health measures	Shorten reassessment interval	Establish repeated multidomain observations

†Proposed evidence-status categories; they are not graded welfare outcomes.

A proposed life-course welfare architecture

The proposed architecture contains five analytically separate fields: exposure history, current multidomain state, adaptive response, recovery opportunity, and future vulnerability. Exposure history records timing and clustering without assuming equal weights. Current state integrates physical, behavioural, affective, and relational evidence. Adaptive response distinguishes observable adjustment from inferred welfare neutrality. Recovery opportunity describes the environmental, clinical, social, and temporal conditions available for restoration. Future vulnerability asks whether residual effects may modify the next transition.

Three boundaries organize interpretation. The compensation boundary is crossed when maintaining function appears to require sustained welfare-relevant cost. The recoverability boundary separates plausible restoration from persistent, relapsing, or uncertain change. The escalation boundary identifies configurations requiring prompt intervention or end-of-life deliberation. These boundaries are proposed and have no validated numerical thresholds.

Evidence supports dynamic welfare assessment, asynchronous adaptation, and context-dependent resilience [19, 22, 23]. The article newly argues that these processes should be arranged as a recurrent life-course state field rather than an additive burden score. **Figure 1** compresses this logic while preserving uncertainty, reciprocal effects, and reassessment.

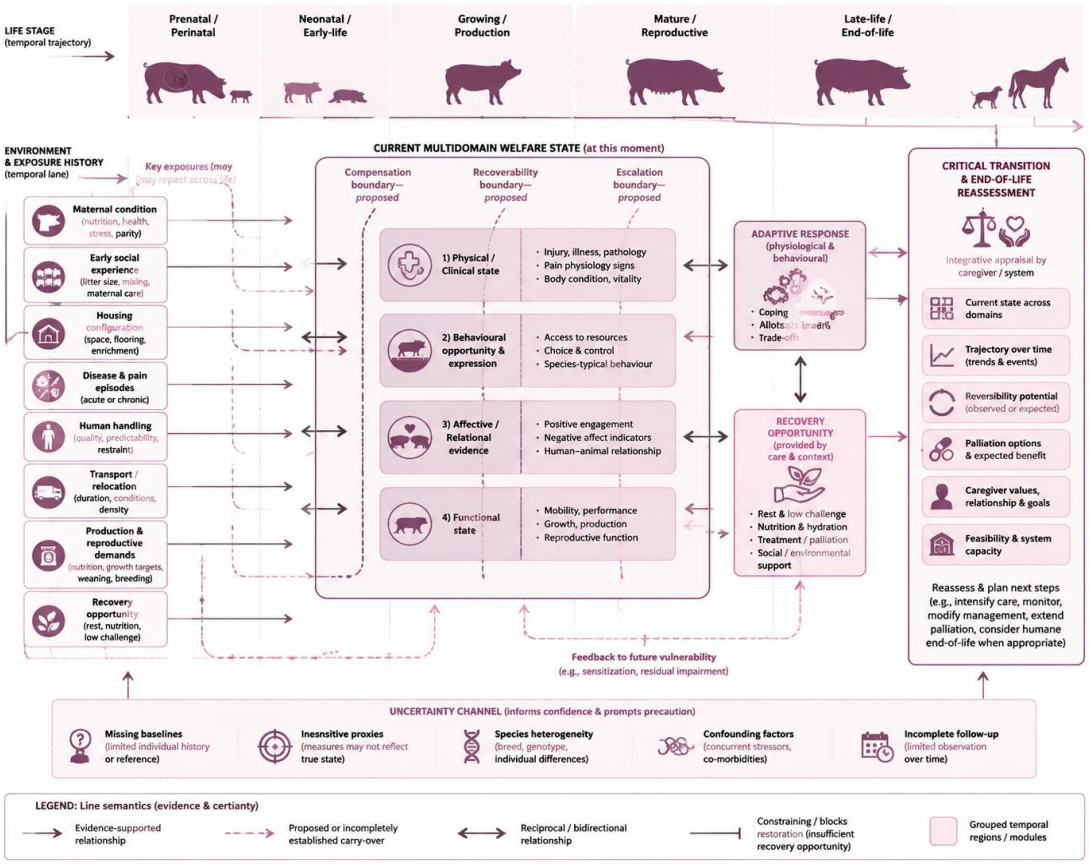

Figure 1. When apparent stability ceases to represent welfare: trajectory states, interrupted recovery, and escalation across the animal life course

Critical transition points

A critical transition point is proposed here as a period when clustered demands threaten available adaptive capacity, recovery is interrupted, or the consequences of delay become materially important. It is not defined by one biomarker or a fixed threshold. Birth, weaning, painful procedures, regrouping, transport, parturition, disease recurrence, loss of mobility, and terminal decline may become critical under some configurations but remain manageable under others.

Veterinary palliative-care scholarship identifies pain management, the meaning of a good death, and caregiver needs as central research priorities, while acknowledging that the evidence base remains limited [25]. Criticality should therefore be judged from trajectory, current suffering, likely reversibility, feasible support, and time sensitivity.

The framework requires accelerated reassessment when indicators deteriorate across domains, previously effective recovery no longer occurs, successive transitions become harder to tolerate, or necessary interventions themselves impose substantial burden. It does not determine which action is ethically sufficient. Instead, it makes explicit why apparently similar events may justify different urgency for animals with different histories, reserves, environments, and realistic recovery opportunities.

End-of-life welfare decisions

End-of-life decisions are longitudinal because the present state acquires meaning from disease course, prior response to treatment, recurrence, remaining behavioural opportunity, and probable future experience. Stakeholder research in old or chronically ill horses demonstrates that quality-of-life judgments vary across owners and professionals and incorporate different interpretations of suffering, function, and acceptable prolongation [26]. Disagreement should be examined rather than concealed within an apparently objective score. Canine survey evidence further indicates that euthanasia was associated with illness, medical symptoms, and lower reported quality of life rather than chronological age alone after adjustment [27]. This supports rejection of age as a sufficient criterion, not rejection of age-related vulnerability.

The proposed decision architecture asks whether suffering can be relieved, whether recovery is plausible, what burdens continued intervention imposes, and which valued activities or relationships remain accessible. Caregiver capacity and treatment feasibility affect what can be delivered but do not redefine the animal's experience. The architecture structures deliberation; it neither mandates euthanasia nor establishes that natural death, palliation, or continued treatment is universally preferable.

Measurement and validation priorities

Longitudinal assessment requires a clear welfare construct before indicators are selected. Welfare-methodology scholarship distinguishes definition, evaluative framework, and assessment tool, warning that tools become difficult to interpret when those stages are conflated [28]. Validation of this architecture must therefore test its proposed constructs rather than merely demonstrate reliable data collection.

Indicator selection should preserve coverage of relevant welfare consequences while considering redundancy, practicality, and measurement burden [29]. Temporal sensitivity should be added: indicators must detect meaningful change, persistence, and recovery at intervals suited to the species and exposure. On-farm measurement reviews further show that animal-based indicators, proxies, and proposed gold standards each have limitations, supporting repeated triangulation rather than reliance on one measure [30].

Necessary studies include prospective cohorts beginning early in life, within-animal transition studies, multimodal recovery tracking, preregistered external validation, and comparisons with simpler repeated cross-sectional models. Falsification is essential: the framework should be revised or rejected if exposure history and recovery information do not improve interpretation, prediction, or decision consistency beyond current assessment, or if proposed states cannot be measured reliably across independent populations.

Conclusion

Welfare is not adequately represented by the animal's present appearance, event count, production level, or chronological age. The proposed life-course architecture links exposure history, current multidomain state, adaptive response, recovery opportunity, and future vulnerability while preserving positive experience and uncertainty. It distinguishes adaptation from welfare neutrality, functional return from multidomain recovery, and persistent compromise from unverified reversibility. Critical transitions and end-of-life decisions are interpreted through trajectory and feasible recovery rather than isolated thresholds. The architecture is an organizing proposal, not a validated score or decision rule. Its value depends on prospective testing, species-specific measurement, transparent boundaries, and evidence that longitudinal interpretation improves welfare decisions without concealing heterogeneity or converting ethically important distinctions into unsupported arithmetic.

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