



The Research Foundation to Tree Pruning: A Review of the Literature

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Abstract. Two hundred one research publications including 152 journal articles were compiled. Forty-four journals were represented with the *Journal of Arboriculture*, *Arboricultural & Urban Forestry*, and *Arboricultural Journal* as the most frequently cited. Compartmentalization, wounding, wound response, decay development, and wound treatment were the most frequently noted topic areas.

The bibliography was organized in Zotero, an application using the Firefox web browser. Keywords were identified for each publication. Where either the article or its abstract was available, an annotation was created. This paper describes the major topic areas identified in the review and discusses the future directions for pruning research.

Key Words: Tree Pruning; Literature Review.

Pruning is at the heart of arboriculture, one of the most important services arborists provide. To paraphrase Alex Shigo (1989), pruning can be one of the best things an arborist can do for a tree and one of the worst things an arborist can do to a tree. Pruning impacts both tree health and structure. It is practiced worldwide.

In 2007, the International Society of Arboriculture (ISA) contracted HortScience, Inc. to prepare a literature review on the topic of pruning. The focus of the review was the research literature. The emphasis was on arboriculture but the review could reference forestry and pomology literature as appropriate.

MATERIALS AND METHODS

In developing the review, the authors focused on peer-reviewed sources, particularly scientific journals. The process was initiated by compiling references from standard industry references such as Gilman's *Illustrated Guide to Pruning* (2nd edition, 2002), and *Arboriculture* (Harris et al. 2004). The authors also relied on O'Hara's review of the forestry literature dealing with pruning and wounding (2007). The online archive of the *Journal of Arboriculture* and *Arboriculture & Urban Forestry* were searched for titles containing the word "pruning." There were 42 citations, some of which appeared prior to 1990—a period when articles in the *Journal of Arboriculture* were not necessarily research based. Major industry standards used in the U.S. (ANSI 2008) and Europe (British Standards Institute 1989; ZTV-Baumpflege 2001; European Arboricultural Council 2008) were then reviewed as well as their supporting publications (Gilman and Lilly 2002; Kempter 2004; Lonsdale 2008).

ISA specifically requested an effort to access literature from non-English sources. Literature from outside North America was queried in several ways. First, two English-language journals published in Europe, the *Arboricultural Journal* (Arboricultural Association, UK) and *Urban Forestry and Urban*

Greening (Springer) were reviewed. This approach yielded good results with Schwarze et al. (2007) and Dujeseifken (2002) as examples. Second, links to non-English publications were searched. Finally, a draft of the literature review was sent to scientists in Germany, Denmark, Italy, and France for comment. Additional references were then incorporated.

There were limitations to this approach. First, journals published in languages other than English were generally inaccessible. Second, papers where pruning was not a keyword may have been missed. Third, journals with limited exposure and nonpublished dissertations were likely omitted. Fourth, no commercial or university databases were used.

Zotero (www.zotero.org) was selected as the bibliographic management program. The program links to Firefox's Mozilla web browser. For each citation, keywords (called "tags" in Zotero's lexicon) were identified. In addition, an annotation ("note" in Zotero) was prepared (Table 1). The breadth of both keywords and annotation was limited by access to the complete paper. *Journal of Arboriculture* and *Arboriculture & Urban Forestry* were unique in that the online archive was completely accessible to members of the International Society of Arboriculture. Older issues can be accessed without membership. Most journals, however, were not fully accessible. In almost all cases, abstracts were used. Approximately 75% of the citations had access to the full article. In the remaining 25%, annotations were either very limited or not entered.

DESCRIPTION OF THE CITATIONS

Two hundred one citations were assembled. Among this group were 20 books and 10 book sections. These had broad focus and were included to identify general resources. For the professional arborist, Gilman (2002) is likely to be the best reference as it covers all aspects of the topic from young trees to mature specimens, in a variety of settings. The book is also well-illustrated.

Table 1. Examples of annotations included in the literature review.

Gilman, E.F., and G. Knox. 2005. Pruning type affects decay and structure of crapemyrtle. <i>Journal of Arboriculture</i> 31:38–47.	Established <i>Lagerstroemia</i> × Natchez trees were topped, pollarded or unpruned for four years. Topping resulted in more dead stubs and discolored wood than pollarding which had limited decay development. Recommended developing pollards rather than routine topping. Nice photos. Florida US.
Neilsen, W., and E. Pinkard. 2003. Effects of green pruning on growth <i>Pinus radiata</i> . <i>Canadian Journal of Forest Research</i> . 33:2067–2073.	Crowns of 6- to 8-year-old, plantation Monterey pine were raised. Raising to 45% of tree height had no effect on growth which was reduced with greater crown removal. Suggests maintaining a live crown ratio of 55%. Tasmania Australia.
Schwarze, F., J. Gruner, M. Schubert, and S. Fink. 2007. Defence reactions and fungal colonization in <i>Fraxinus excelsior</i> and <i>Tilia platyphyllos</i> after stem wounding. <i>Arboricultural Journal</i> 30:61–82.	Describes the anatomy of the barrier zone (= CODIT wall 4), suggesting that differences in this zone account in part for species differences in decay resistance. Strong within species variation in discoloration associated with both increment borer holes and chain saw cuts to the stem. Also isolated fungi from around the wounds. Excellent photos. Good discussion of fungal development and tree response. Freiburg Germany.

Forest tree pruning was represented by Mayer Wegelin's papers (1936; 1952), the silvicultural textbook of Smith et al. (1996), and a Hanley et al. (1995) volume on pruning of conifers. Also referenced were resources written in German (Hoster 1993; Dujesiefken 1995; Pfisterer 1999; Stobbe et al. 2002a; Stobbe et al. 2002b), and French (Drenou 1999; Austad and Hauge 2007). Palms were referenced through Broschat and Meerow (2000). For the most part, books were included as general references to the topic of pruning but lacked extensive references to the scientific literature.

Journal articles comprised 152 of the 201 citations. Forty-four journals were referenced, published in 12 countries (Table 2). *Journal of Arboriculture* (51), *Arboriculture & Urban Forestry* (12), and *Arboricultural Journal* (9) were the most frequently referenced. Journals cited originated in Europe (25), North America (17), and the Asia-Pacific region (2).

More than half of the journals (24) were focused on forestry and forest science. Another 10, such as *American Journal of Botany*, were oriented to the traditional plant sciences. Three journals were horticultural in focus; another five were oriented to arboricultural and urban forestry. Two journals, *Trees—Structure and Function* and *Tree Physiology*, crossed lines among forestry, arboriculture, and horticulture.

Citations arose primarily from English language journals (113 of 201). Some journals, notably *Arboriculture & Urban Forestry*, *Arboricultural Journal*, *Canadian Journal of Botany*, *Canadian Journal of Forest Research*, and *Journal of Arboriculture* may provide abstracts in languages other than English. Also included were citations in French, German, and Italian.

A small fraction of the citations had not undergone the normal peer-review process. Four citations were reports of the USDA Forest Service, all authored by Shigo (Shigo and Larson 1969; Shigo and Marx 1977; Shigo et al. 1979; Butin and Shigo 1981). Such reports are normally reviewed by other scientists within the agency. Articles in *Arborist News*, such as

Fraedrich and Smiley (1996) and Guggenmoos (2007), receive technical review. The nature of the review for books, industry standards, extension publications, conference proceedings, and book sections was unknown. The main reason for including material that had not been peer-reviewed was to highlight a specific pruning topic. This will be discussed in the following section.

A list of all authors was compiled. The most frequently cited authors were Alex Shigo of the United States and Dirk Dujesiefsken of Germany. Both were noted 13 times. Authors cited with four or more references included Ed Gilman, Jason Grabosky, Brian Kane, Dan Neely, and Tom Smiley of the United States; Karen Barry and Elizabeth Pinkard of Australia; W. Liese, D. Eckstein, Francis Schwarze, and Horst Stobbe, of Germany; and Francesco Ferrini of Italy.

MAJOR TOPICS IN PRUNING RESEARCH

Research topics were identified by the frequency with which keywords were applied. The following discussion highlights a portion of the literature included in the bibliography.

The dominant theme of the literature review was wounding, the tree's response and possible treatments to affect that response. Wounding and the tree response, to it were together noted as keywords in 30 of the 201 citations. They were often linked to compartmentalization (24 citations), decay (25), and wound dressing (10). O'Hara (2007) provided a review of the literature on this topic, emphasizing wound response and the goal of producing clear wood in timber.

Modern research activity in this area might begin with Shigo and Larson's (1969) photographic summary of the patterns of discoloration and decay in hardwoods of the northeastern U.S. This report focused on the relationship of external appearance to wood quality. It was observational in nature, rather than founded in experimentation. One finding was that covering pruning wounds with "dressings" neither improved closure nor reduced the presence of decay.

In 1977, Shigo and Marx released their seminal report *Compartmentalization of decay in trees*, which introduced the CODIT concept. Shigo et al. (1979) then reported on the relationship of flush cuts to the development of internal decay and other defects in black walnut (*Juglans nigra*). The authors noted, "When pruning is done late in the life of a tree, care must be taken not to remove the branch collars that form about the bases of dead and dying branches." Also in 1979, Shortle expanded on the compartmentalization model with very well-illustrated paper. He posed the "heartrot" concept, describing how external wounds allow decay fungi to enter and become established in the tree. Development of the CODIT model culminated with two publications: *How tree branches are attached to trunks* (Shigo 1985) and *Compartmentalization: A conceptual framework for understanding how trees grow and defend themselves* (Shigo 1984). As noted previously, the vast bulk of this work was observational in nature.

Shigo was neither the only scientist interested in tree response to wounding nor the first to examine it. For example, foresters have long had an interest in tree response to pruning and wounding (McQuilkin 1950; Herring et al. 1958; O'Hara 2007). Von Aufsess (1975) noted the formation of a protective zone at the base of branches. Neely (1970; 1979) observed that production of callus (i.e., woundwood) at the margins of pruning wounds was related to tree vigor, as measured by growth.

Research on the topic of tree wound response and its management continued through the following decades. Experiments

Table 2. Journals referenced in the pruning bibliography.

Journal	Origin	No. of Citations
Acer	Italy	7
Agroforestry Systems	Netherlands	1
Allgemeine Forstzeitschrift	Germany	1
American Journal of Botany	United States	1
Annals of Applied Biology	United Kingdom	3
Annals of Botany	United Kingdom	1
Annual Review of Phytopathology	United States	1
Arboricultural Journal	United Kingdom	9
Arboriculture & Urban Forestry	United States	12
Biological Conservation	United Kingdom	1
Biotechnology Agronomy Society & Environment	Belgium	1
Canadian Journal of Botany	Canada	1
Canadian Journal of Forest Research	Canada	7
European Journal of Forest Pathology	Netherlands	1
European Journal of Forest Research	Germany	1
Forest Ecology and Management	United States	5
Forest Pathology	United States	1
Forest Science	United States	1
Forestry	United Kingdom	1
Forst und Holz	Germany	1
Forstwissenschaftliches Centralblatt	Germany	3
Holz als Roh- und Werkstoff	Germany	1
Holzforschung	Germany	2
HortScience	United States	3
International Association Wood Anatomy Bulletin	United States	1
Journal of American Society Horticultural Science	United States	2
Journal Applied Ecology	United Kingdom	1
Journal of Arboriculture	United States	51
Journal of Forestry	United States	5
Journal of Wood Science	United States	1
Neue Landschaft	Germany	1
New Forests	United Kingdom	1
New Phytologist	United Kingdom	1
New Zealand Tree Grower	New Zealand	1
Phytopathology	United States	1
Proc. American Society of Horticultural Science	United States	1
Schweizerische Zeitschrift für Forstwesen	Germany	1
Sherwood	Italy	4
Silva Fennica	Finland	2
Tasforests	Australia	1
Tree Physiology	United Kingdom	1
Trees - Structure & Function	Germany	4
Urban Forestry & Urban Greening	Denmark	5
Western Journal Applied Forestry	United States	1

focusing on application of wound dressings generally found materials to be ineffective. There has been excellent work studying the development of reaction and barrier zones in response to wounding of all types. Dujesiefken et al. (1999), Barry et al. (2000), Pearce (2000), Schwarze (2001), and Schwarze et al. (2007) provide detailed, very well-illustrated analyses.

The question of whether to employ flush or natural target (i.e., collar) cuts has generally sided with the latter (Deflorio et al. 2007). O'Hara (2007) suggested that one type or style of cut may not meet all management needs. Researchers tend to agree that smaller pruning wounds are preferable to larger ones, and pruning is most appropriate on young trees.

Research in the area of wound response has also involved examinations of branch structure and strength. Eisner et al. (2002b) characterized the relative size of branch to stem as aspect ratio and used this measure to assess response to pruning. Removal of branches with aspect ratios greater than 0.39 in red maple (*Acer rubrum*) and 0.59 in southern live oak (*Quercus virginiana*) resulted in greater discoloration in the parent. Branches with a more vertical orientation were more likely to have pith continuous with the stem. Removal of limbs with this pith connection resulted

in more discoloration in the parent stem. Gilman and Grabosky (2006) observed that as aspect ratio increased, the amount of discoloration and decay also increased. Another key finding was the observation that pruning can slow down the growth of a codominant stem to the extent that a branch protection zone forms. Another facet of branch structure research has been the documentation that as aspect ratio increases, strength decreases (Gilman 2003; Kane 2007; Kane and Farrell 2008).

At the current time, the Hamburg Tree Pruning System (Dujesiefken and Stobbe 2002; Dujesiefken et al. 2005a) may best represent the evolution of research into wound response. It is based on observations of 750 wounds on 115 mature street and park trees. The system is based on the natural target pruning approach and has been integrated into German standards.

Another important topic encountered in the review was pruning around overhead utility lines (16 citations). The topic first appeared in the *Journal of Arboriculture* in conference papers during the 1980s (Holewinski 1983; Johnstone 1983). Both raised ideas of using what has become known as either natural or directional pruning rather than traditional roundover trimming. Goodfellow et al. (1987) demonstrated that directional pruning resulted in less regrowth than roundover. Johnstone (1988) followed with a description of how directional pruning could be successfully integrated into a utility's vegetation management program. Directional pruning certainly came of age with the publication of *Pruning trees near electrical utility lines* (1990), also known as Shigo's "yellow book." Although it was not a research-based publication, the yellow book became a key element of utility practice. It has largely been superseded by Kempter's (2004) summary of best management practices.

In recent years, research in the utility side of arboriculture has focused on three areas: 1) service reliability (Galvin 2005; Guggenmoos 2007), 2) impacts of pruning on tree structure and stability (Browning and Wiant 1997; Dahle 2006a; Dahle 2006b), and 3) the response of property owners to changes in practice (Close 2001; Kuhns and Reiter 2007).

Outside of the U.S., there has been essentially no research in the utility arboriculture area, at least that which has been published in English language journals. One exception was Millet and Bouchard's (2003) application of the French architectural analysis methods to the utility setting. They suggested species architectural patterns should be considered in making pruning decisions.

Municipal arborists have benefited from research dealing with pruning of street trees (10 citations). In 1981, Miller and Sylvester addressed the question: What is the appropriate length of the pruning cycle for municipal trees? Using Milwaukee, WI, as a test case, they concluded four to five years was the appropriate pruning cycle. They observed that tree condition declined as the length of the pruning cycle increased. Tous-saint et al. (2002) provided a somewhat similar assessment for European linden (*Tilia × europaea*) street trees in France. They

contrasted the costs of routine pruning to those associated with topping, finding the former both less expensive and less damaging in the long-term. Campanella et al. (2009) followed this with an assessment of the long-term costs of roundover, restoration, and thinning of European linden street trees in Belgium.

Nowak (1990) evaluated the results of street tree inventories from 11 tree species in the U.S. He observed strong species-specific results in pruning requirements, suggesting that pruning cycle may be species-specific. American elm (*Ulmus americana*) and boxelder (*Acer negundo*) had the most urgent need for pruning, with London plane (*Platanus × acerifolia*) and honeylocust (*Gleditsia triacanthos* f. *inermis*) the least urgent.

Ehsen (1987) described street tree pruning in Germany with a focus on how pruning needs change over the tree's life-span, moving from a focus on training in young trees to maintenance (e.g., cleaning and raising) on mature trees to reduction in overmature trees. Balder et al. (1997) summarized street tree selection and management in Germany, using Berlin as an example. Mascelli et al. (2008) used street trees in Prato, Italy, as a case study of pruning and management.

The research foundation for the range of types or styles of pruning varies widely. In some areas, research is only now catching up with long-time practice. In others, research provided clear direction to practice. Where to make cuts and the need to use wound dressings is but one example. The methods for, and value of, pruning young trees to develop good structure has been well-documented whether pruning involves retaining low branches (Leiser et al. 1972), or selective bud removal (Oleksak et al. 1997).

In contrast, other pruning practices have less well-developed foundation. There is no research to suggest crown thinning improves either tree health or structural stability. And, while it has been common practice for many years, reduction pruning to a branch at least one-third the diameter of the stem lacked a scientific basis. It was not until Grabosky and Gilman (2007) evaluated reduction cuts on two mature oak species that a tentative basis could be established.

The architectural style of pruning is common in France (Stefulesco 1995; Drenou 1999; Drenou 2000). In many ways, research has followed practice, as this pruning technique is quite old. Timing and techniques of architectural pruning have been elucidated by the research of scientists such as Bory et al. (1996) and Clair-Maczulajtys et al. (1999) who have focused on carbohydrate storage patterns in trees. Pollards are also a common feature of the European landscape. Both Austad and Hauge (2007) and Ferrini (2006c) discuss their physiology and management.

Much of the work with crown-raising has occurred in forestry, where the objective is to have the lower trunk free of branches. From Slabaugh (1957) to Neilsen and Pinkard (2003), research has documented that removal of up to 50% of the live crown of young trees by lifting does not adversely impact growth. In summarizing the results from 8 field studies with Douglas-fir (*Pseudotsuga menziesii*), O'Hara (1991) suggested 33% crown removal as the limit.

Pruning is considered one of the important tools in the practice of plant health care. Svihra (1994) summarized the literature regarding eradication pruning (i.e., the removal of infested and infected branches). Pruning has been used to manage disease problems such as Dutch elm disease (Gregory and Allison 1979) and oak wilt (Appel 1994; Camilli et al. 2007). It

is also important in the management of bronze birch borer (Ball 1992) and bark beetles (Barger and Cannon 1987). One of the key results of such work is the knowledge that many insects are attracted to fresh pruning wounds. For this reason, pruning should take place when insects are not active.

Arborists have long believed that proper pruning reduced the likelihood of damage during storms. Duryea et al. (1996) documented the effects of Hurricane Andrew in Florida, supported this observation for some species. Luley et al. (2002) documented branch failures in sweetgum (*Liquidambar styraciflua*) trees in Rochester, NY, over an eight-year period. Pruning did not reduce the number of failures (most of which occurred while the tree was in leaf), but did result in fewer service requests. Kane (2008) examined the pattern of tree failure following a severe windstorm in Massachusetts finding that pre-storm pruning "had little effect on (tree) failure."

Pruning has been used as a tool in evaluating tree response to wind, particularly related to the affect on trunk movement. Smiley and Kane (2006), Pavlis et al. (2008), and Gilman et al. (2008a; 2008b) simulated wind conditions to evaluate trunk movement of young trees in response to crown thinning, raising and reduction pruning. Both crown reduction and crown thinning reduced trunk movement (Gilman et al. 2008a; Gilman et al. 2008b) and wind load (Smiley and Kane 2006). Essentially, the more crown mass removed, the lower the trunk movement or wind load. Gilman et al. (2008a) noted the response was a complex one, and the authors cautioned against extrapolating to larger trees.

Moore and Maguire (2005) examined the effects of crown-raising on movement of 14 m to 20 m Douglas-fir trees. Natural sway frequency increased as pruning level increased, although this was not noticeable until 80% of the canopy had been removed. Changes in sway frequency were related to how crown mass was distributed. They noted that treating branches as a lumped mass may not be appropriate.

Standards for pruning are found in the U.S. (ANSI 2008), the United Kingdom (British Standards Institute 1989), and Germany (ZTV-Baumpflege 2001). In each case, the standard provides a common vocabulary and procedures for pruning activities. In the U.S., the International Society of Arboriculture (Gilman and Lilly 2002; Kempter 2004) produced a companion volume to the standard, aimed at defining best practice. In a somewhat similar manner, the European Arboricultural Council (2008) recently updated the *European Tree Pruning Guide*. In Italy, the concept of industry standards remains under discussion (see di Lobis 2003).

RESEARCH TOPICS FOR THE FUTURE

Arboricultural practice should have a foundation in research. In the area of pruning, a foundation is present to some extent. It seems clear that employing removal and reduction cuts has been documented by experimentation and careful observation. Research by Shigo and more recently by Dujesiefken has supported use of the branch collar, natural target approach to selecting the location of a removal cut. Although less well-defined, the same is true for reduction pruning, primarily through work of Ed Gilman and Jason Grabosky.

In utility arboriculture, reduction cuts take the form of directional pruning—the effort to use a tree's natural growth pattern to aid in maintaining clearance. The literature documents the value of directional pruning and the problems as-

sociated with topping and traditional roundover trimming. Future research could further validate the few experiments in this area. In addition, research along the line of Millet and Bouchard's (2003) application of architectural analysis to line clearance would enhance the idea of directional growth.

Additional research is needed to support the use of pruning in the area of plant health care. Although effectiveness of sanitation or eradication pruning has been documented, use of cleaning and thinning to improve overall plant health has not. In a similar manner, an answer to the question, "Does pruning reduce the potential for windthrow, windsnap, or failure during storms?" has not yet been developed. Most recent research has been with relatively small trees rather than mature individuals. A recent article by Kane and Harris (2008) reviews the research on this topic.

Access to non-English language journals and those in fields such as forestry is ever-increasing but is not without its limitations. First, many but not all journals have some online presence. Abstracts can generally be accessed free of charge. Articles, however, must be purchased. A second limitation to a broader application of the world-wide literature is the lack of a common vocabulary. Is early pruning the same as formative pruning? Is forestry's green pruning equivalent to crown raising? Comparison of professional standards will reduce confusion about terms. A third limitation is language, as only few journals provide abstracts in other languages. Fewer still offer table and figure captions in a second language.

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Résumé. Deux cents une publications de recherches, incluant 152 articles de journaux, ont été compilés. Quarante-quatre journaux étaient représentés, et le *Journal of Arboriculture*, le *Arboricultural & Urban Forestry* ainsi que le *Arboricultural Journal* étaient les plus fréquemment cités. La compartimentation, les blessures, la réaction aux blessures, le développement de la carie et le traitement des blessures étaient les sujets les plus fréquemment traités.

La bibliographie a été montée sur Zotero, une application faisant appel au navigateur Firefox. Les mots-clés ont été identifiés pour chacune des publications. Lorsque l'article ou le résumé était disponible, une annotation a été inscrite. Cet article décrit les sujets majeurs traités qui ont été identifiés dans cette revue et présente une discussion des directions futures en ce qui regarde l'élagage.

Zusammenfassung. 201 Forschungspublikationen, einschließlich 152 Journalartikel wurden zusammengestellt. 44 Journale, einschließlich *Journal of Arboriculture*, *Arboricultural & Urban Forestry*, und *Arboricultural Journal* als die meist zitierten, wurden präsentiert. Kompartimentalisierung, Verletzung, Wundreaktion, Fäuleentwicklung und Wundbehandlung waren die häufigsten Themen.

Die Bibliographie wurde in Zotero organisiert, eine Applikation von dem Browser Firefox, welcher die Schlüsselworte in jeder Publikation identifiziert. Wo entweder der Artikel oder sein Abstrakt erhältlich war, wurde ein Vermerk gemacht. Diese Studie beschreibt die Hauptthemengebiete, die in der Durchsicht identifiziert wurden und diskutiert die zukünftigen Richtungen für die Baumpflege.

Resumen. Se compilaron 201 publicaciones de investigaciones incluyendo 152 artículos de journal. Cuarenta y cuatro journals estuvieron representados por el *Journal of Arboriculture*, *Arboricultural & Urban Forestry*, y *Arboricultural Journal* como los más frecuentemente citados. Compartimentación, herida, respuesta a la herida, desarrollo de la descomposición y tratamiento de heridas fueron los tópicos más frecuentes. La bibliografía estuvo organizada en Zotero, una aplicación que usa el navegador Firefox. Se identificaron palabras claves para cada publicación. Cuando el artículo o su abstract estuvieron disponibles, se creó una anotación. Este trabajo describe los tópicos principales identificados en la revisión y discute las direcciones futuras para la investigación sobre la poda.

APPENDIX. LITERATURE REVIEW

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